

Effects of age on learning a spatial motor task in younger and
older adults individualizing their knowledge of results schedule

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DEDICATION

To my mom, dad and my sister Melissa

A B S T R A C T

Self-controlled KR practice has revealed that providing participants the opportunity to control their KR is superior for motor learning compared to participants replicating the KR schedule of a self-control participant, without the choice (e.g., yoked). The purpose of the present experiment was two-fold. First, to examine the utility of a self-controlled KR schedule for learning a spatial motor task in younger and older adults and second, to determine whether a self-controlled KR schedule facilitates an increased ability to estimate one's performance in retention and transfer. Twenty younger adults and 20 older adults practiced in either the self-control or yoked condition and were required to push and release a slide along a confined pathway using their non-dominant hand to a target distance. The retention data revealed that as a function of age, a self-controlled KR schedule facilitated superior retention performance and performance estimations in younger adults compared to their yoked counterparts.

Key words: self-control, knowledge of results (KR), younger adults, older adults, motor learning

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CHAPTER 1: REVIEW OF LITERATURE

1.1 Motor learning and augmented information

The execution of motor skills occurs throughout the life of humans. These motor skills begin to develop early in childhood (e.g., crawling and walking) and as one ages, new skills are developed (e.g., driving a car) while retained skills continue to be refined. Motor skills are a fundamental aspect of human life and the measurement of these skills is crucial to understanding the factors facilitating human performance (Voelcker-Rehage, 2008). However, it is important to distinguish between motor development, motor learning, and motor control. Motor development refers to the sequential changes in motor behaviour and the continuous processes (e.g., maturation and aging) which underlie these changes (Clark & Whittall, 1989). An example of motor development is the progression for an infant to sit independently (Malina, Bouchard & Bar-Or, 2004). Motor learning is defined as a set of internal processes associated with practice, leading to a relatively permanent change in one's ability to perform a motor skill (Schmidt & Lee, 2005). An example of motor learning would be learning to juggle three balls as a result of practice and being able to transfer this learning to juggling different objects, such as bowling pins. Therefore, the main distinction between motor learning and motor development is the changes are associated with practice or training rather than aging or maturation. Motor control is the study of how the central nervous system is organized to control and coordinate movements based on sensory information from the environment and/or the body (Schmidt & Lee, 2005). The study of human movement is examining the interactive relationship between the study of how movements are controlled (motor control) and how movements are learned (motor learning) (Schmidt & Lee, 2005).

Learning cannot be directly observed and must be inferred through performance on a retention test. A retention test measures mastery of a task by an individual following a specified period of time once practice is completed (Magill, 2004). The immediate retention test will reveal any initial differences in learning as a result of the experimental manipulations experienced during the practice period, such as different KR frequency schedules. The delayed retention test is critical as performance on this test will reveal whether relatively permanent changes have occurred in the ability to perform the skill, and whether it can be inferred that learning has occurred. Therefore, the delayed retention test occurs approximately 24 hours after the practice phase as it has been demonstrated that sleep has an integral role in the consolidation of a motor skill (Walker, Brakefield, Morgan, Hobson & Strickhold, 2002). The number of retention tests can vary from one study to the next (e.g., Bruechert, Lai & Shea, 2003 – 1 test: delayed 24 hours; Patterson & Carter, 2010 – 2 tests: immediate 15 minute & delayed 24 hours]; Sidaway, August, York & Mitchell, 2005 – 3 tests: immediate 10 minute, delayed 24 hours & delayed one week); however, two retention tests are typically used: an immediate and a delayed retention. Again, the length of time following the end of practice to when each of these tests are administered varies. To illustrate motor learning, consider the following example. An individual is performing a golf putt where the cup is surrounded by three concentric rings each worth a different value. A putt that stops in the outer ring is worth one point, the middle is worth two points, the inner is worth three points, and a hole in one is worth five points. The goal of the task is to score as high as possible with five putts. If the individual was only able to score 10 points at the end of practice, and scored a total of 13 points in a delayed retention, this would indicate an improvement in motor performance, and therefore learning could be inferred.

The acquisition of motor skills can be expedited through various types of practice contexts. Augmented information has produced learning benefits across a variety of motor skills.

Augmented information refers to the sources of information that are available to a performer before the action (e.g., the position of your limbs), during the action (e.g., the way the movement feels), and after the action (e.g., the movement outcome within the environment) (Schmidt & Lee, 2005). The information from these different points within a movement can be demonstrated by hitting a golf ball with a gap wedge to a target that is 100 yards away. Before the action, the position of the performer's hands on the wedge would provide tactile information regarding grip technique while kinesthetic information would be available during the action from the position of the limbs, trunk, and head at club impact. Finally, the location of where the ball lands (e.g., knowledge of results) would provide information upon movement completion. Augmented information can be viewed as a broad term in motor learning that can be subdivided into inherent feedback and augmented feedback. Inherent or intrinsic feedback refers to the abundance of information that is naturally available in the task that is not provided from an external source (Sidaway et al., 2005). Therefore, intrinsic feedback can be derived from vision, audition, tactile and/or proprioception. In contrast, augmented or extrinsic feedback is presented to the learner from an external source and can be provided during and/or after a movement (Sidaway et al., 2005). Augmented feedback can be subdivided into knowledge of performance (KP) and knowledge of results (KR). KP is information regarding the movement characteristics of the performer (Salmoni, Schmidt & Walter, 1984; Sidaway et al., 2005) whereas KR is feedback regarding the accuracy of a response outcome relative a task goal (Magill, 2004). An example of KP would be a physical therapist informing a client to bend their knees more as they walked while retraining their gait after an injury. The scores provided to a figure skater after a routine by a panel of judges would be an example of KR.

Both KP and KR can have an integral role in the acquisition of motor skills; however, KR has received a significant amount of attention in motor learning research and next to practice

itself, is viewed as the most important practice variable determining motor skill acquisition (Newell, 1977; Salmoni et al., 1984).

1.2 The theoretical role of knowledge of results in motor learning

Understanding the role of KR in the acquisition of motor skills has proven to be a fruitful, yet challenging inquiry. Early accounts of the role of KR in motor learning confused the temporary performance effects of KR during acquisition as learning; a methodological limitation (see Salmoni et al., 1984 for a review). KR has been accepted as one of the most important practice variables determining skill acquisition (Newell, 1977; Salmoni et al., 1984) that early examinations of KR concluded that learning could not occur without it (Bilodeau & Bilodeau, 1958; Bilodeau, Bilodeau & Schumsky, 1959). Over the past decades, motor learning theories have highlighted the role of KR during motor skill acquisition and concluded its primary role was to resolve errors between the participant's actual performance and the desired performance (Adams, 1971; Schmidt, 1975).

Adams (1971) proposed that motor learning is a problem-solving process and KR was the information that an individual utilized to develop strategies to form a correct response (e.g., the perceptual trace). Adams (1971) closed loop theory of motor behaviour consisted of two memory components: the memory trace and the perceptual trace. The role of the memory trace, which preceded the use of the perceptual trace, was to select and initiate a motor response. The perceptual trace determined the extent of the movement and served as an evaluation mechanism through the development of a reference of correctness. The perceptual trace strengthened as a function of KR; therefore, KR after all trials was essential to learning. Adams (1971) closed loop theory was formulated from the findings of slow moving tasks and was expected to generalize to

fast moving tasks. Providing KR after every trial was believed to be vital to strengthening the perceptual trace because a weak perceptual trace would produce errors and prevent learning.

Schmidt (1975) proposed a new theory of motor learning, referred to as the schema theory. The schema theory was proposed to remedy some of the difficulties and limitations of Adams (1971) closed loop theory; however, some similarities between the two theories exist. The schema theory is based on the notion that every time an individual performs a movement, four pieces of information will be stored: the initial conditions, the response specifications for the motor program, the sensory consequences of the movement, and the outcome of the movement (Schmidt, 1975). The relationship and interaction of these four sources of information are used by the performer to construct the two main components of the schema theory: the recall schema (equivalent to the memory trace) and the recognition schema (equivalent to the perceptual trace). The recall schema is used to generate a motor program to perform the movement and is developed based on the relationship between the desired movement outcome and the initial conditions prior to the movement. The recognition schema is based on the relationship between the expected sensory consequences of a movement and the actual outcome. Similar to the perceptual trace from the closed loop theory, the strength of the recognition schema increases with the quality and quantity of intrinsic feedback and KR received on each trial. Consistent with Adams (1971), Schmidt (1975) believed that KR was necessary after all trials; however, errors were not assumed to be detrimental to learning as Adams (1971) believed. Instead, errors would update the error labelling system (e.g., subjective reinforcement) to improve the ability to accurately label future errors by strengthening the schema for response recognition (Schmidt, 1975).

The biggest challenge facing previous motor learning theories was the role of no-KR trials during practice. Interestingly, the traditional views on the role of KR during motor skill

acquisition (Adams, 1971; Schmidt, 1975) have been challenged by studies that have revealed practice with a lower relative frequency of KR compared to KR after every trial may be more beneficial for learning and retention of various motor skills (Ishikura, 2008; Steinhauer & Grayhack, 2000; Winstein & Schmidt, 1990, experiments 2 and 3). Ishikura (2008) examined the effects of a 100% KR schedule and a 33% relative KR frequency schedule for learning to putt in golf. Participants were required to putt a golf ball to a goal line that was located 3.5 m from the starting position. Participants in the 33% KR condition performed more accurately (measured by |CE|) in an immediate and delayed retention test. Ishikura (2008) concluded that the poor scores exhibited in retention by the 100% KR condition was the result of a less developed movement-produced feedback system due to a greater reliance on KR during practice. Steinhauer & Grayhack (2000) investigated the influence different KR frequency schedules would have on learning a vowel nasalization task where participants were required to nasalize a sustained vowel to a target score of 80%. Participants were randomly assigned to a 100% KR, 50% KR, or a no KR group. In both the retention and transfer test, participants that received 50% KR (after every other trial) were more accurate (measured by |CE|) and more consistent (measured by VE) than participants that received 100% KR. Steinhauer & Grayhack (2000) concluded that when KR was provided after every trial, it became integrated into the task that it prevented participants from interpreting their own intrinsic feedback, consistent with Ishikura (2008).

Experiments two and three in Winstein & Schmidt (1990) examined the influence that a systematically reduced number of KR trials over practice (e.g., faded KR schedule) would have on retention performance with no-KR trials (experiment two) and trials when KR was provided (experiment three). The faded-KR schedule used in both experiments had a relative KR frequency of 50%; however, the proportion of KR trials was higher early in practice compared to the later trials in practice. Participants were randomly assigned to either the faded-KR schedule or the

100% KR schedule. On the delayed no-KR retention test in experiment two, a faded-KR schedule facilitated significantly less error (indexed by root mean squared [RMS] error) than a 100% KR schedule. To determine whether the enhanced performance of the faded-KR condition in retention was the result of a similarity in structure between their practice and the retention test, experiment three replicated the methodology of experiment two; however, a delayed KR retention test was used. Consistent with the findings from retention in experiment two, the faded-KR condition performed with significantly less error (measured by RMS error). Winstein & Schmidt (1990) concluded that a faded-KR schedule was more beneficial in the development of intrinsic error detection mechanisms than a 100% KR schedule.

During practice, participants in a reduced KR frequency schedule experience no-KR trials, considered to prevent further learning by Adams (1971) and Schmidt (1975) because the perceptual trace and recognition schema cannot be sufficiently updated to produce a more accurate response on the subsequent trial. However, the increased learning by participants in a reduced relative frequency of KR schedule (Ishikura, 2008; Steinhauer & Grayhack, 2000; Winstein & Schmidt, 1990, experiments 2 and 3) suggests that some form of feedback that is intrinsic to the motor task provides sufficient information to facilitate performance and learning when KR is not available to the learner. Consequently, Salmoni et al. (1984) re-examined the nature of KR and highlighted the limitations of previous research of KR and proposed that KR may serve a guiding role during motor skill acquisition.

1.3 The guidance hypothesis

The guidance hypothesis has been proposed to explain the dual nature of KR in the learning of various motor skills. In an extensive review and re-evaluation of past KR studies, Salmoni et al. (1984) revealed some significant limitations in the experimental design and

interpretation of the role of KR during skill acquisition. Salmoni et al. (1984) noticed conclusions were derived from acquisition performance and not measures of retention (Lee, Swinnen & Serrien, 1994; Salmoni et al., 1984; Wulf & Shea, 2004). If results from performance in practice are inferred as learning rather than from retention and transfer tests, the performance-learning paradox is very likely to occur. This paradox states that a practice variable may facilitate successful performance during practice but on a retention test, performance significantly decreases, whereas poor performance during acquisition may result in greater performance on a retention test (Schmidt & Lee, 2005). The guidance hypothesis states that frequent KR schedules can have both positive and negative effects on performance and learning. During practice, 100% KR schedules will guide the participant to the correct response; thus facilitating acquisition performance. Participants experiencing KR after every trial often become dependent on it, causing the participant to ignore intrinsic sources of feedback that are critical to developing error detection and correction capabilities when KR is no longer available (Bruechert et al., 2003; Salmoni et al., 1984; Sidaway et al., 2005; Wishart & Lee, 1997; Wulf & Shea, 2004). Moreover, when KR is withdrawn (e.g., in retention and transfer tests), a detrimental impact on learning is revealed by participants who practiced with 100% KR when learning simple motor tasks. Therefore, according to the tenets of the guidance hypothesis, a KR schedule should be a balanced integration of intrinsic and extrinsic sources of feedback to avoid dependency on KR while facilitating independent learners.

1.4 Older adults and knowledge of results

The acquisition of motor skills through various KR schedules has been studied extensively in younger adult populations (Guadagnoli & Kohl, 2001; Kohl & Guadagnoli, 1996; Lai & Shea, 1999; Lee & Carnahan, 1990; Weeks & Kordus, 1998; Winstein & Schmidt, 1990).

Research examining the interaction of KR and older adults is limited in the motor learning literature. A summary of the existing literature follows.

Swanson & Lee (1992) examined the effects of providing KR in a blocked or a random schedule on the acquisition and retention of a barrier knock down task with an associated movement goal time. Younger and older adults were randomly assigned to either the blocked or random feedback conditions. Participants in the blocked KR schedule received KR regarding the same segment for blocks of 30 trials whereas in the random KR schedule, KR was provided for one of the three segments in a randomized order. During acquisition, the younger adults performed the task more accurately and with less variability than the older adults, irrespective of KR condition. Overall, the younger adults were more accurate (measured by $|CE|$) and more consistent (measured by VE) than the older adults in retention. However, irrespective of age, participants in the random KR schedule were more accurate than the blocked feedback condition in the retention period. In both acquisition and retention, there were no interactions of age with any of the experimental variables. Swanson & Lee (1992) suggested two possible reasons for the differences in performance accuracy. First, younger adults were able to interpret and process KR more effectively than older adults which resulted in better learning of the task. The alternative reason was that younger adults were better at timing accuracy (measured by $|CE|$) but both age groups processed KR in a similar fashion. Swanson & Lee (1992) support this explanation by the absence of an age and KR group interaction for $|CE|$ during acquisition and retention. Therefore, Swanson & Lee (1992) concluded that younger and older adults use KR in a similar fashion to acquire a novel motor task.

Similar to Swanson & Lee (1992), Carnahan, Vandervoort & Swanson (1996) were also interested in determining if older adults utilize KR similar to younger adults. Participants were randomly assigned to either a 100% KR condition or a summary KR condition. The summary

length was five trials; therefore, participants would complete five trials and upon completion of the fifth trial would receive KR for all five trials. For the experiment, participants were required to learn a four digit key pressing sequence with a specified goal time. During acquisition, the participants who received KR after every trial were more accurate in achieving the movement goal time, as indexed by |CE|. However, 100% KR caused the older adults to have more variability in their responses (measured by VE) whereas KR scheduling did not differentially impact movement variability of the younger adults. Interestingly, performance accuracy was a function of KR scheduling during retention, irrespective of age. The summary KR conditions were more accurate (|CE|) in achieving the temporal goal of the task. In agreement with Swanson & Lee (1992), Carnahan et al. (1996) concluded that older adults demonstrated similar learning to younger adults in a summary KR schedule.

Wishart & Lee (1997) investigated age-related differences in learning a three segment barrier knock down task. Each segment of the task had a specific timing goal. Participants were randomly assigned to one of three feedback conditions: 100% KR, 67% KR that was faded over trials, and 67% KR that was faded over the segments within each trial. During acquisition and retention, the younger adults were more accurate (indexed by |CE|) and more consistent (indexed by VE) than the older adults regardless of KR schedule. However, age-related performance differences were not identified in the transfer test. Based on the absence of an interaction between age and KR group in acquisition, retention and transfer, Wishart & Lee (1997) concluded the younger and older adults utilized KR in a similar way to learn the barrier knock down task, consistent with Swanson & Lee (1992) and Carnahan et al. (1996).

Rice (2003) examined the interaction between task complexity and varying frequencies of KR for the acquisition, retention and transfer of a motor skill in older adults. The experimental task required participants to turn a knob back and forth to match the height of their bar on the

computer screen to the height of the target bar. Participants were randomly assigned to one of four conditions based on task complexity (easy or hard) and feedback frequency (100% or 33%). The target level for the hard conditions oscillated within a range using the following duration and target levels: 2000ms-10mm, 550ms-20mm, 250ms-15mm, 750ms-35mm, 1250ms-5mm, 200ms-30mm, and 2000ms-15mm. The duration and target levels for the easy condition were 1000ms-10mm, 1000ms-35mm, 1000ms-10mm, 1000ms-35mm, 1000ms-10mm, 1000ms-35mm, and 1000ms-10mm. During acquisition, the younger and older adults that received feedback after every third trial demonstrated greater performance irrespective of task difficulty than the 100% KR groups. No significant differences or interactions were found in retention; however, the 33% KR hard group had the lowest cumulative absolute error. Cumulative absolute error was determined by the absolute difference between the target level and the performance bar level for a given trial. For the transfer test, the 33% KR hard group was significantly more accurate than the other three conditions. Rice (2003) believed that the combination of a hard task with a low KR frequency required older adults to encode information more efficiently, resulting in the 33% KR hard group generalizing their learning to a novel variation of the motor task from acquisition than the other three conditions. However, a limitation to this study was the absence of younger adult participants to allow for age-related comparisons in skill acquisition.

van Dijk, Mulder & Hermens (2007) examined the impact of KR and kinematic feedback on acquisition and learning of a complex motor task in younger and older adults. Participants were randomly assigned to either a KR schedule or a kinematic feedback schedule to learn an isometric force production task. The kinematic feedback was provided to participants by overlaying the produced force onto the target wave form. KR was displayed as the average absolute error. Both forms of feedback were displayed at the end of the trial. During acquisition and retention, participants that received kinetic feedback were more accurate than those receiving

KR. However, in both acquisition and retention, no significant interactions between age and feedback type were noted. van Dijk et al. (2007) also concluded that the effects of augmented feedback on learning a motor task are similar in younger and older adults.

The role of terminal and concurrent visual feedback for learning a novel bimanual coordination pattern was examined by Wishart, Lee, Cunningham & Murdoch (2002). The novel bimanual coordination pattern required participants to perform a 90° relative phase pattern. Younger and older adults were randomly assigned to one of the two feedback conditions where KR was provided during (concurrent group) or after (terminal group) every trial. The participants who received concurrent KR were more accurate (indexed as absolute mean error score) during retention. Furthermore, younger adults performed the 90° pattern with less variability (indexed by standard deviation) than the older adults. Age-related differences were revealed in retention as younger adults were able to learn the new pattern with both terminal and concurrent KR while older adults benefited more from concurrent KR compared to terminal KR. Wishart et al. (2002) concluded that older adults are more sensitive to their practice environment when learning a bimanual task and this may be the result of a diminished capacity to inhibit the influence of inherent bimanual patterns (e.g., in-phase and anti-phase) and a difficulty in interpreting intrinsic feedback to produce the 90° pattern.

Chiviawsky, Wulf, Wally & Borges (2009) replicated a study by Chiviawsky & Wulf (2007) that examined the impact that providing KR after *good* trials compared to after *poor* trials would have on learning a motor task in younger adults. Chiviawsky et al. (2009) attempted to replicate the findings from Chiviawsky & Wulf (2007) in an older adult population. Chiviawsky & Wulf (2007) found that providing feedback after *good* trials resulted in greater learning than feedback after *poor* trials in younger adults. Therefore, in Chiviawsky et al. (2009), older adults were randomly assigned to either the *good* or *poor* feedback condition.

Participants in the *good* feedback condition received feedback on their best three trials within a six trial block whereas the *poor* feedback condition received feedback on their worse three trials within a six trial block. Participants were required to throw a beanbag at a concealed target located on the floor using their non-dominant hand. The target had a radius of 100 cm with 10 concentric rings each worth a specific value from 10 to 100 points. The target area was worth 100 points with the point value of each ring decreasing as you moved away from the target. A throw that did not land within any area on the target was scored as zero points. On a three day retention test, the older adults that received feedback after *good* trials had significantly higher accuracy scores; thus Chiviacowsky et al. (2009) replicated the findings of Chiviacowsky & Wulf (2007). Therefore, it can be concluded that younger and older adults both benefit from KR regarding successful trials when learning a novel motor task.

1.5 Knowledge of results and intrinsic error detection mechanisms

KR is a powerful practice variable that can have both positive and negative effects on motor learning. The motivational role of KR can be viewed as a positive effect because when KR is available, participants tend to be more interested in the task and are willing to work harder (Arps, 1920; Crawley, 1926; Elwell & Grindley, 1938 as cited in Salmoni et al., 1984). In contrast, the informational nature of KR results in a dependency on KR to guide upcoming responses (e.g., the guidance hypothesis), a negative impact on learning (Salmoni et al., 1984). Therefore, a KR schedule that is advantageous for learning should help to eliminate any discrepancies between the participant's intrinsic feedback and their actual performance (Anderson, Magill & Sekiya, 2001; Bruechert et al., 2003; Salmoni et al., 1984; Sidaway et al., 2005; Winstein & Schmidt, 1990).

Winstein & Schmidt (1990) examined the effects of different relative frequency of KR schedules in three experiments. In experiment one, participants practiced in either a 100% or 33% KR relative frequency condition for learning a spatiotemporal goal movement pattern. Participants completed the pattern by manipulating a lever with their right hand without vision. This task was used in all three experiments. A retention test was performed 10 minutes after the practice phase. During retention, participants were randomly assigned to one of four retention conditions, 0%, 33%, 66%, or 100% KR relative frequency. Interestingly, no significant differences were found between the 100% and the 33% KR conditions during practice. Winstein & Schmidt (1990) suggested that a less frequent KR schedule may not be as detrimental to acquisition performance as previously thought. The retention tests also did not reveal any significant effects; however, the 33% condition was slightly more accurate than the 100% condition in all four retention tests.

The purpose of experiment two was to test one of the tenets of the guidance hypothesis that states that a higher frequency of feedback should be more beneficial early in practice while a decreased KR schedule would be more effective later in practice. To test this, participants practiced in either a 100% KR condition or a 50% KR condition where the relative frequency of KR was systematically decreased over practice trials with more KR provided early in practice (termed a faded KR schedule). Participants who experienced a faded KR schedule during practice performed with greater accuracy on a delayed retention test compared to the participants that received feedback after every trial in practice. Winstein & Schmidt (1990) concluded that other factors besides the number of KR presentations must be influencing learning.

Based on the results of experiment two, experiment three examined the possibility that learning was the result of the faded KR condition experiencing no-KR trials during acquisition. Therefore, the same methodology of experiment two was repeated during acquisition; however,

the delayed retention test included KR. Similar to experiment two, the faded KR condition performed more accurately on the delayed retention test with KR than the 100% KR condition. Based on the findings from the three experiments, Winstein & Schmidt (1990) suggested the 100% KR condition developed a dependency on extrinsic sources of KR, consistent with the guidance hypothesis. However, this dependency does not occur in lower relative KR frequency conditions and as a result, the learner may be more likely to interpret their intrinsic sources of feedback for error detection and correction.

Anderson et al. (2001) investigated the effects on learning an aiming task through a no delay KR condition and a two trial delay KR group. The participants in the no delay KR condition received their KR directly after their response. The participants in the two trial KR delay group received KR for trial one after trial 3, KR for trial two after trial four and so on. In addition, Anderson et al. (2001) examined whether the effects the two KR manipulations would have on learning would be maintained if the inherent response produced feedback was modified. The intrinsic feedback was modified by the addition of a spring mechanism to the aiming task. Therefore, participants were randomly assigned to one of four conditions based on KR manipulation (no delay or two trial delay) and intrinsic feedback manipulation (spring or no spring). During acquisition, the two trial delay groups were less accurate than the no delay conditions. The results of a 24 hour retention test revealed the two trial KR delay groups were more accurate (indexed by radial error) than the no delay groups and that the no spring conditions were more accurate than the conditions with the spring mechanism. A significant interaction between KR delay and intrinsic feedback revealed that the no spring two trial KR delay group was more consistent (indexed by radial variable error) than all other conditions. Anderson et al. (2001) concluded that delaying the provision of KR is beneficial to skill acquisition but modifying the inherent feedback in a task with a spring mechanism made the intrinsic feedback

unfamiliar and too difficult to use. However, it is important to note that the use of intrinsic sources of feedback was not directly measured in this study; therefore, a detailed understanding of the mechanisms responsible for the greater learning in the trial delayed KR conditions is unknown.

Bruechert et al. (2003) examined if practicing in a reduced KR relative frequency condition would facilitate an increased ability to detect the direction and magnitude of response errors. A unique methodological element in this study is that unlike previous studies that manipulated error estimation during acquisition (e.g., Guadagnoli & Kohl, 2001; Swinnen, Schmidt, Nicholson & Shapiro, 1990), the authors were interested in determining if a reduced KR schedule would facilitate the development of enhanced error detection capabilities in retention. Participants were required to complete three force production tasks in a serial order using their non-dominant hand and practiced in either a 100% or a 50% KR condition. The 50% KR condition performed more accurately (measured by total error) and with less variability (indexed by VE) during acquisition. This trend was maintained in retention as the 50% KR condition remained more accurate and more consistent with their responses. During retention, all participants were asked to verbally estimate their force production error after each trial. The participants in the 50% KR group made significantly more accurate error estimations compared to the 100% KR condition. Bruechert et al. (2003) concluded that a reduced KR relative frequency schedule is more effective in developing an intrinsic error detection mechanism than a high frequency KR schedule.

Sidaway et al. (2005) investigated whether a high frequency of intrinsic visual feedback would influence learning to a similar extent that a high extrinsic (KR) frequency schedule would, as predicted by the guidance hypothesis (Salmoni et al., 1984). Participants were randomly assigned to one of six experimental conditions that differed in the type of feedback that was

provided (visual or verbal KR) and the relative frequency it was provided (10, 50, or 100%). Visual KR was provided by permitting the participants to view the target and the result of their throw on feedback trials. Extrinsic KR was provided verbally and included the number of the scoring zone the beanbag landed in and whether it was short or long relative to the zero error zone. The 100% frequency viewed or received feedback after every trial, the 50% frequency viewed or received feedback for the first five trials in each block of 10 trials and the 10% frequency viewed or received feedback on the first trial in each block of 10 trials. The experimental task was a beanbag toss to a target located on the floor of a racquetball court. All participants were not allowed to see the target while throwing the beanbag. The target consisted of a zero error target zone that was surrounded by 20 scoring zones (10 short of the zero error zone and 10 past the zero error zone labelled ± 1 to ± 10). During acquisition, higher frequencies of feedback, irrespective of type facilitated a higher degree of performance accuracy (indexed by $|CE|$). A significant interaction between frequency and type of feedback revealed that the 100% extrinsic KR condition was more accurate than all other extrinsic KR conditions during acquisition. The results from the delayed retention test revealed that regarding visual KR, a 10% feedback schedule facilitated greater learning while the 100% visual KR exhibited the lowest accuracy. Furthermore, similar to the 100% visual KR condition, the 100% extrinsic KR group were less accurate in retention compared to the other two extrinsic KR conditions. Sidaway et al. (2005) concluded that high KR relative frequency negatively impacts learning and this impact is similar for both intrinsic and extrinsic forms of feedback.

1.6 Self-selected strategy use in cognitive and verbal learning

Research in the cognitive and verbal learning literature has investigated the strategic preferences of older adults compared to younger adults for learning cognitive tasks, primarily the noun-pair lookup task. Although this thesis is concerned with older adults learning a motor task,

cognitive effort has an important influence on learning (Lee et al., 1994) and the cognitive and verbal learning literature provides insight into the preferred practice environment of older adults when provided the opportunity to self-select a learning strategy.

Rogers, Hertzog & Fisk (2000) investigated the relationship between cognitive strategies and performance in younger and older adults in the noun-pair lookup task. To complete the noun-pair lookup task, participants can utilize a visual scanning strategy or a retrieval strategy to determine whether the target noun-pair matches a pair located in the lookup table. Both strategies can be used successfully; however, use of the retrieval strategy produces faster reaction times (Rogers et al., 2000). The visual scanning strategy is considered to require low cognitive investment while the retrieval strategy is much more demanding on cognitive resources. When given the opportunity to choose a strategy, older adults were more likely to utilize the visual scanning strategy; resulting in slower reaction times than younger adults.

Touron & Hertzog (2004) conducted three experiments to examine differences in strategy selection and memory ability confidence between younger and older adults. Experiment one examined how item knowledge influenced strategy choice and subsequent performance in the noun-pair lookup task. Participants were randomly assigned to either a memory probe condition (10 noun-pairs with memory probes and 10 without) or a no memory probe condition (20 noun-pairs without memory probes). Upon completion of each trial, participants were asked to indicate what strategy they relied on during the previous trial: visual scanning, retrieval, both or other. Younger adults responded consistently faster than the older adults for the noun-pair trials. Interestingly, the memory probe older adult condition responded quicker than their no probe counterparts. The younger adults reported using the retrieval strategy more often than older adults but the older adults who practiced with memory probes reported using the retrieval strategy more often than those without memory probes. Touron & Hertzog (2004) concluded that older adults

were less likely to use the retrieval strategy than the younger adults, but the avoidance of this effortful strategy could not be attributed to decreased noun-pair knowledge.

Experiment two examined whether age-related differences in noun-pair performance was the result of an associative learning deficit. To test this, half of the participants memorized 50% of the noun-pairs to be presented during practice while the other participants memorized all the noun-pairs. Despite pre-learning either 50% or all of the noun-pairs, older adults remained more reluctant to shift to the retrieval strategy. Although the older adults in the 100% pre-learn condition reported using the retrieval strategy more often than those in the 50%, the frequency of retrieval use was considerably less than that of the younger adults.

The third experiment in Touron & Hertzog (2004) utilized a similar protocol to that in experiments one and two. Younger adults responded consistently faster than older adults due to a greater reliance on the retrieval strategy, consistent with experiments one and two. Touron & Hertzog (2004) concluded the metacognitive variables in experiment three indicated the older adult's preference for the least effortful strategy is primarily associated with low confidence in the ability to successfully use the retrieval strategy for the noun-pair lookup task.

Touron, Hoyer & Cerella (2004) examined cognitive skill learning in two experiments where younger and older adults had to solve novel arithmetic problems. Participants could adopt either a computation or a retrieval strategy to solve the equations. When the computation strategy is utilized, participants apply a rule or an algorithm to obtain the solution to a problem. Touron et al. (2004) were interested in determining when younger and older adults shift from a computational strategy to a retrieval strategy in experiment one. Participants were randomly assigned to the 0%, the 33% or the 100% strategy probe condition where the strategy probe instructed the participant to report whether a recently completed response was made using

computation, memory retrieval or other. Participants had to verify whether the equation $A \# B = C$ was true or false. Regardless of strategy probe, older adults not only reported significantly less use of the retrieval strategy but also a significantly slower rate in shifting to retrieval use.

Experiment two attempted to replicate the findings of experiment one using a production task (e.g., $A \# B = ?$) rather than a verification task (experiment one) while examining how two forms of pre-training would influence the shift from computation to retrieval use. Participants were randomly assigned to item pre-training, rule pre-training, or a control condition. In the item pre-training condition, participants were required to enter responses to $A \# B = ?$ with no information regarding the $\#$ operator. Participants in the rule pre-training condition were instructed in the use of the $\#$ operator sign for the equation $A \# B = ?$. The control condition responded to equations in the form $? \# ? = C$ by entering the two-digit number given for C . Overall, younger adults had significantly faster response times due to a greater reliance on retrieval use.

Hertzog, Touron & Hines (2007) assessed response time monitoring in younger and older adults and the influence of feedback on estimation accuracy in experiment one. Participants were randomly assigned to a feedback or no feedback condition. The participants in the feedback condition received their actual response time latency on every other trial. Younger adults reported using memory retrieval more often than the older adults which resulted in significantly faster responses. Response time feedback facilitated more accurate estimations; however, younger adults were overall more accurate in estimating their response times than the older adults. Older adults underestimated response times for the visual scanning strategy which was not attenuated through practice or feedback. Older adults also underestimated response time for the retrieval strategy, but not to the same degree as the visual scanning strategy.

The purpose of experiment two was to investigate age-related differences in monitoring response times for the visual scanning strategy only. To ensure that a visual scanning strategy could only be used, participants completed a varied noun-pair task where noun pairings were randomly shuffled from trial to trial. The feedback manipulations and the protocol for estimations from experiment one were replicated in experiment two. Younger adults responded significantly faster and were more accurate in monitoring response times than older adults. Feedback facilitated more accurate estimations for both levels regardless of age. Experiment two revealed that older adults are ineffective at monitoring their response times for the visual scanning strategy and this deficiency is magnified when feedback is not provided.

The final experiment in Hertzog et al. (2007) examined age-related differences in memory retrieval latency for an associative memory task without concurrent visual search. Participants were required to make a judgement of learning immediately after studying each pair which required them to estimate the probability that they would remember the pair in 10 minutes. Interestingly, neither age nor feedback had an effect on associative recognition accuracy or mean judgements of learning. Younger adults responded faster than older adults and were more accurate in monitoring their response times, consistent with experiments one and two. Hertzog et al. (2007) concluded that older adults demonstrate a time-monitoring deficit through a tendency to consistently underestimate response times in cognitively effortful tasks.

1.7 Self-controlled practice for motor skill learning

The learning advantages associated with allowing participants to individualize a portion of their practice context, termed self-controlled practice, are generally viewed as robust. The benefits of self-controlled practice in the acquisition of motor skills have primarily been examined in healthy younger adult populations and more recently in healthy children

(Chiviawsky, Wulf, de Medeiros, Kaefer & Wally, 2008a; Chiviawsky, Wulf, de Medeiros, Kaefer & Tani, 2008b; Sanli & Patterson, 2009). The superiority of self-controlled practice environments have been demonstrated in the contexts of controlling the frequency of augmented feedback (Chen, Hendrick & Lidor, 2002; Chiviawsky & Wulf, 2002, 2005; Chiviawsky et al., 2008a; Chiviawsky et al., 2008b; Janelle, Kim & Singer, 1995; Janelle, Barba, Frehlich, Tennant & Cauraugh, 1997; Patterson & Carter, 2010; Patterson, Carter & Sanli, in press), the use of assistive devices (Hartman, 2007; Wulf & Toole, 1999), the frequency of observing a model (Wrisberg & Pein, 2002; Wulf, Raupach & Pfeiffer, 2005), and the organization of practice repetitions (Keetch & Lee, 2007; Sanli & Patterson, 2009; Wu & Magill, 2004). When learners are afforded the opportunity to control a portion of their practice, it has been demonstrated that self-control facilitated greater learning compared to their yoked counterparts. A yoked participant replicates the practice schedule of a self-control participant without the choice. For example, if a self-control participant requested KR after trials one, four, eight and ten, the yoked participant that is matched to this self-control participant would also receive KR after the same four trials whether they wanted KR or not. The yoked condition is essential to research on self-controlled practice in motor learning because it determines whether any potential learning is the result of being actively involved in controlling a practice variable like KR (e.g., SELF > YOKED) or due to the relative frequency of that practice variable (e.g., SELF = YOKED).

1.7.1 Self-controlled augmented feedback schedules in younger adults

Janelle et al. (1995) examined whether allowing participants to control their receipt of performance feedback (KP) would be more beneficial in learning an underhand ball toss task compared to KP that was presented according to a pre-determined or random schedule. Sixty younger adults practiced in either a no feedback control condition, a 50% KP condition (e.g., feedback every other trial), a summary KP group (five trial summary length), a self-controlled KP

group or a yoked condition. Participants completed an underhand ball toss to a target located on the floor. The goal area of the target was surrounded by concentric rings with a perfect toss landing in the goal area worth zero points. The value of each concentric ring of the target progressing outward from the goal area increased by one unit in value; therefore, scores could range from zero to 11. The participants that controlled their feedback performed significantly better in retention compared to the yoked condition, and the experimenter-defined feedback schedules (indexed by absolute error). Interestingly, Janelle et al. (1995) found that the participants in the self-controlled condition only requested feedback on an average of 7% of the total trials, and concluded the self-control condition did not become reliant on KP. Although it was not directly measured, Janelle et al. (1995) speculated the self-control condition was able to utilize intrinsic sources of information in the absence of performance feedback to learn the motor task.

Janelle et al. (1997) conducted a similar study to that of Janelle et al. (1995). Janelle et al. (1997) examined the influence of self-controlled KP on the acquisition of a motor skill compared to a yoked condition, a summary KP condition and a KR only condition. Participants threw a standard tennis ball at a target located on the floor using their non-dominant hand. Similar to Janelle et al. (1995), Janelle et al. (1997) determined that participants in the self-controlled KP condition outperformed all other experimental conditions during the retention period of the experiment. The relative frequency that KP was required by the self-control condition decreased over the acquisition phase with KP being requested on an average of 11.5% of the total acquisition trials. Janelle et al. (1997) concluded that participants in the self-controlled KP condition processed information more efficiently based on being actively involved in the individualization of their practice context. Janelle et al. (1997) suggested that learners afforded the opportunity to individualize their practice environment increases motivation to learn because

the learner has the freedom to implement different strategies during practice, a luxury that may not be available with a more rigid feedback schedule.

Chen et al. (2002) investigated whether similar learning effects would be found for learning a five digit key pressing sequence between a self-controlled KR schedule and an experimenter-induced KR schedule. Participants were randomly assigned to the self-control condition, the experimenter-induced condition, or one of the two yoked conditions for each KR manipulation. The self-control condition had complete control on their receipt of KR whereas in the experimenter induced condition, participants were presented with a reminder asking if they wanted KR regarding their just completed response. The immediate and two day retention tests revealed that participants who actively decided when to receive and not to receive KR were more accurate (indexed by |CE|) than their yoked counterparts in achieving the timing goal of the task. In accordance with the conclusions of Janelle et al. (1997), Chen et al. (2002) believed that participants in self-control conditions are free to engage in various individualized learning strategies during skill acquisition. This increased responsibility to learn may have implicitly increased the intrinsic motivation of these participants which in turn had an advantageous effect on their cognitive processes.

Chiviakowsky & Wulf (2002) also examined the learning differences between participants who controlled their receipt of KR compared to a yoked condition. The participants in this experiment were required to learn a four digit key pressing sequence with three relative timing goals and an absolute timing goal. Chiviakowsky & Wulf (2002) did not find any differences in retention performance between the self-control and yoked conditions; however, the self-control condition performed greater (indexed by AE) than their yoked counterparts on a delayed transfer test utilizing a longer timing goal. Chiviakowsky & Wulf (2002) included a questionnaire in their experiments in hopes of acquiring a better understanding of the underlying

mechanisms associated with the effectiveness of self-controlled practice. At the end of the acquisition phase, all participants completed a multiple choice KR questionnaire. Participants in the self-control condition were asked when and why they asked for feedback and when they did not ask for KR. The yoked condition participants were asked if they thought they received KR after the right trials and if not, when they would have preferred to receive KR. The questionnaire data revealed that the majority of participants in the self-control condition preferred to receive KR after a perceived good trial. Interestingly, the majority of yoked participants believed they did not receive KR after the right trials, and they would have also preferred to receive KR after a perceived good trial. It was also determined that the subjective measures of the self-control condition corresponded to their behavioural measures (AE) when errors on KR trials were found to be lower than no-KR trials during the acquisition. Chiviacowsky & Wulf (2002) proposed that an inherent motivational factor may be responsible for the learning benefits of self-controlled practice, as it is easier to repeat a successful movement rather than correct for errors after a poor trial. As a result, this may have motivated participants to be actively engaged in their learning process to produce successful responses.

Chiviacowsky & Wulf (2005) facilitated our understanding of the learning benefits derived from a practice environment where the learner is provided control by manipulating when the participant decided to receive feedback or not, either prior to the trial or after the trial. Participants practiced the same four digit key pressing task from Chiviacowsky & Wulf (2002) with the same relative timing goals and absolute timing goal. The participants who decided whether KR was needed after a trial performed with less relative timing error on a retention test compared to the group that decided prior to completing the trial; however, this performance difference did not reach statistical significance. When participants were required to generalize their learning to a novel variation of the task, the experimental group that decided after a trial to

receive KR during acquisition performed with significantly less relative timing error. The results of this study led Chiviawsky & Wulf (2005) to conclude that error estimation processes are necessary to assess a just completed response, and may have an important role in the learning benefits associated with self-controlled practice.

Patterson & Carter (2010) examined the advantages of a self-controlled KR schedule for learning three different five digit key pressing sequences each with a different associated movement goal time. Participants in the self-control condition decided if KR was required after each trial while participants in the yoked condition replicated the KR schedule of a self-control participant, without the choice. The self-control condition was significantly more accurate (indexed by %|CE|) with respect to movement goal times than their yoked counterparts in both retention and transfer tests. Participants also completed a questionnaire regarding feedback preference as used in Chiviawsky & Wulf (2002). A preference for feedback after perceived good trials was found for all three different sequences. Patterson & Carter (2010) concluded that participants in the self-control condition adopted a generalized learning strategy for the three different key pressing sequences.

Patterson et al. (in press) examined the impact of decreasing the proportion of self-control trials during the acquisition of a five digit key pressing sequence. Participants were required to complete the key pressing sequence as close as possible to the associated timing goal. The first 30 participants were randomly assigned to one of three self-control conditions (SELF-SELF, ALL-SELF or FADED-SELF) that differed in the number of control trials experienced during acquisition (50% or 100% of trials). Participants in the SELF-SELF condition controlled their KR schedule for all 90 acquisition trials whereas the ALL-SELF condition received 100% KR for the first 45 trials followed by 45 self-control trials. For the FADED-SELF condition, the frequency of KR was reduced over the first 45 practice trials (100% KR for trials 1-15; 33% KR for trials 16-

30; and 20% KR for trials 31-45) followed by 45 self-control trials. The remaining 30 participants were randomly assigned to one of three respective yoked conditions (YOKED-YOKED, ALL-YOKED or FADED-YOKED) and replicated the KR schedule of a self-control counterpart. In retention and transfer, no significant differences were found between the three self-conditions. Consistent with Chen et al. (2002) and Patterson & Carter (2010), the self-control conditions performed more accurately (indexed by |CE|) and more consistently (indexed by VE) in retention. In addition, the self-control conditions also performed more accurately in transfer, consistent with Chiviacowsky & Wulf (2002; 2005). Patterson et al. (in press) concluded that a self-controlled KR schedule was beneficial for learning the key pressing task and the proportion of control trials experienced during acquisition did not differentially impact motor learning in younger adults.

1.7.2 Self-controlled observation of a model presentation in younger adults

Wrisberg & Pein (2002) examined the efficacy of allowing participants to control their frequency of observing a model presentation for learning a sport related task. Participants were required to learn the badminton long serve in either 100% observation prior to an attempt, a self-control condition or a no observation condition. On a retention test, Wrisberg & Pein (2002) found that the self-control condition and 100% observation condition demonstrated similar accuracy scores measured by the Poole long serve test and similar technique scores rated by a judge comparing the participant's technique to the model. However, a limitation to this study was the absence of a yoked condition. Therefore, it is unclear whether the frequency the model was viewed or the ability to decide when to view the model was responsible for performance during retention.

Wulf et al. (2005) also examined self-controlled observation of a model presentation, but addressed the methodological limitation in Wrisberg & Pein (2002) by incorporating a yoked

condition in the experiment. Similar to Wrisberg & Pein (2002), Wulf et al. (2005) used a sport task where participants were required to perform jump shots from the free throw line on a basketball court. Both groups showed improvements in their accuracy and form scores during acquisition; however, the self-control condition was significantly more accurate and had better form in retention than their yoked counterparts. Wulf et al. (2005) suggested that future studies involving model presentation with self-controlled practice should include questionnaire data to determine why and when self-control participants request a demonstration during skill acquisition

1.7.3 Self-controlled use of assistive devices in younger adults

Wulf & Toole (1999) examined the effects of a self-controlled practice context involving physical assistive devices for learning a complex motor skill compared to a yoked condition. Participants were required to produce ski slalom movements on a ski simulator by moving a platform as far as possible from side to side, with larger amplitudes indicating superior performance. During acquisition, the self-control condition was able to decide if they required assistance from ski poles to perform the task. No significant differences were found in practice, but the self-control condition performed the ski slalom task with significantly larger amplitudes than their yoked counterparts in retention when the option of physical assistance from the ski poles was not available. Similar to Janelle et al. (1997) and Chen et al. (2002), Wulf & Toole (1999) believed the learning benefits of self-control in this practice environment originated from the opportunity to explore various strategies with and without the ski poles during practice to facilitate skill acquisition.

Hartman (2007) conducted a similar study to Wulf & Toole (1999). Instead of requiring participants to perform ski slalom movements, participants had to balance on a stabilometer. Participants practiced in the self-control condition or the yoked condition where the self-control

condition was able to decide when they wanted to use a balance pole while performing the task during acquisition. The yoked condition had no choice regarding when a balance pole would be used because they replicated the use of the balance poles of a self-control participant. The self-control condition performed significantly better than the yoked condition during acquisition and retention. Hartman (2007) incorporated a modified version of the questionnaire used in Chiviacowsky & Wulf (2002). The questionnaire data revealed that the majority of self-control participants preferred the use of the balance poles when they attempted a new strategy. Interestingly, the majority of yoked participants did not feel like they used the poles on the right trials and that they would have preferred to use the balance poles when attempting a new strategy. Hartman (2007) concluded that self-control resulted in superior learning because self-controlled practice allows participants to actively engage in and evaluate various performance strategies throughout practice.

1.7.4 Self-controlled repetition schedules in younger adults

Wu & Magill (2004) examined self-controlled practice repetitions for learning a golf putting task with three distances (1.5ft, 3ft, and 4ft). During acquisition, participants practiced in a self-control condition where they chose the distance to putt from on each trial while the remaining participants practiced in a yoked condition. The self-control condition made significantly more accurate putts than their yoked counterparts on a five minute and a 24 hour serial transfer test. Wu & Magill (2004) concluded that providing learners with the opportunity to individualize the order of practice trials may have engaged the learner in cognitive processes that enhanced motor skill learning.

Keetch & Lee (2007) examined the impact of self-controlled practice utilizing both a simple and a complex task. The experimental task required participants to use a computer mouse

to complete a pattern sequence displayed on a computer screen. Throughout the pattern, the participant was required to stop in each square only long enough to make either a left or right mouse click. In addition, participants were required to complete the easy pattern sequences using their dominant hand and the hard pattern sequences using their non-dominant hand. Self-controlled practice did not facilitate any advantage during acquisition but retention data revealed the self-control condition to have the most improved performance irrespective of task difficulty. Keetch & Lee (2007) concluded that self-control may be advantageous for learning because the learners are able to individualize their practice environment based on their own needs.

1.7.5 Self-controlled knowledge of results in children

The learning benefits associated with allowing younger adults to control the delivery of augmented feedback (e.g., KR and KP) are well supported. Chiviacowsky et al. (2008a) compared the effects of a self-controlled high-KR frequency schedule to a self-controlled low-KR frequency schedule for learning a beanbag tossing task using the non-dominant hand in children. The two KR frequency conditions were determined after the KR schedules were individualized by the children during acquisition. The target and scoring system were identical to that used in Chiviacowsky & Wulf (2007). All participants increased their accuracy based on points during acquisition; however, the accuracy scores on the one day retention test revealed the self-controlled low-KR frequency group were significantly less accurate than the self-controlled high-KR frequency condition. Therefore, a self-controlled high-KR frequency schedule was more beneficial for learning in children. Chiviacowsky et al. (2008a) suggested the self-controlled high-KR frequency was beneficial because of age-related differences. First, children are inherently less experienced than younger adults, therefore their sources of intrinsic feedback, which are vital to error detection and correction are less developed. Consequently, a greater amount of extrinsic KR would compensate for this limited experience. Lastly, a high KR

frequency may compensate for a decreased information processing ability in children compared to younger adults. However, a limitation to the specific age-related conclusions of Chiviakowsky & Wulf (2008a) between children and younger adults is that their experiment did not include any younger adult participants.

Chiviakowsky et al. (2008b) completed a similar study to Chiviakowsky et al. (2008a) using the same underhand beanbag tossing task, target and scoring system. However, rather than comparing two self-control conditions, Chiviakowsky et al. (2008b) compared children who controlled their receipt of KR to an age-matched yoked condition. During acquisition, both conditions improved their accuracy scores with practice. Although feedback questionnaires were not administered as in Chiviakowsky & Wulf (2002), it was noted the self-control participants asked for feedback after relatively good trials compared to poor trials. This was determined during data analysis as indicated by greater accuracy scores on KR trials compared to no-KR trials. The participants who requested feedback when desired during acquisition performed with significantly more accuracy than their yoked counterparts on the one day retention test. Chiviakowsky et al. (2008b) concluded the learning benefits of self-controlled practice generalized to children and that the main learning benefit of a self-controlled feedback schedule may be motivational.

1.7.6 Self-controlled repetition schedules in children

Sanli & Patterson (2009) examined the impact of self-controlled practice in children as well as younger adults. Participants practiced three different spatiotemporal key pressing sequences in a self-control condition or a yoked condition. Sanli & Patterson (2009) found that irrespective of age, participants who were afforded the opportunity to control the order in which

they practiced the three different key pressing sequences performed significantly better than their yoked counterparts in retention.

1.7.7 Self-controlled knowledge of results in older adults

Although self-controlled practice has facilitated learning of various motor skills, research providing older adults with the opportunity to control an aspect of their practice environment is very limited. Currently, there is only one study that has investigated whether older adults benefit similarly to younger adults and children when practicing in a self-controlled context. Patterson, Sanli & Adkin (2009) examined the effects of age when participants were afforded the opportunity to individualize their receipt of KR for learning a walking task. Interestingly, Patterson et al. (2009) did not replicate the previously found learning advantages of a self-controlled practice environment in both self-control conditions. The authors suggest that it was the frequency of KR rather than the decision to receive KR that was the main factor that facilitated motor performance in the experiment.

Although Patterson et al. (2009) were unable to replicate the learning benefits of self-controlled practice from previous motor learning studies in an older adult population; this does not suggest that older adults are incapable of succeeding as autonomous learners for motor skill acquisition. Rather, it remains inconclusive whether the older adults may benefit from the opportunity to individualize their practice since it has been well established that younger adults are capable of creating effective KR schedules (Chen et al., 2002; Chiviacowsky & Wulf, 2002, 2005; Patterson & Carter, 2010), but the younger adults in Patterson et al. (2009) failed to do so. Therefore, future motor learning studies examining self-controlled practice should continue to utilize an older adult population to determine if the learning advantages of self-controlled practice found in younger adults and children persist in older adults.

Self-control has been revealed as a powerful motor learning variable. Whether participants control the delivery of augmented feedback, the frequency of observing a model presentation, the use of assistive devices or the order of practice repetitions, learning is enhanced compared to their yoked counterparts as measured in retention and transfer tests. Although the superiority of a self-controlled practice environment is well documented for a variety of practice contexts as well as different classifications of motor skills, a limiting factor in its generalizability is that these findings are predominantly found in younger adults and more recently, children, and are inconclusive in older adults.

CHAPTER 2: INTRODUCTION

2.1 Introduction

Research examining the learners' opportunity to control and individualize a portion of their practice environment, defined as self-controlled practice, has recently become a prevalent focus in motor learning research (Chiviacowsky & Wulf, 2002, 2005; Chiviacowsky et al., 2008a; Chiviacowsky et al., 2008b; Hartman, 2007; Janelle et al., 1995; Janelle et al., 1997; Keetch & Lee, 2007; Patterson & Carter, 2010; Patterson et al., in press; Patterson et al., 2009; Patterson & Lee, 2010; Sanli & Patterson, 2009; Wrisberg & Pein, 2002; Wu & Magill, 2004; Wulf et al., 2005; Wulf & Toole, 1999). When learners are afforded this opportunity, it has been demonstrated that self-control facilitated greater learning compared to their yoked counterparts, who replicate the practice context created by a self-control participant, without the choice. The superiority of a self-controlled practice environment in younger adults has been demonstrated in such practice contexts such as controlling the frequency of receiving augmented information (Chen et al., 2002; Chiviacowsky & Wulf, 2002, 2005; Chiviacowsky et al., 2008a; Chiviacowsky et al., 2008b; Janelle et al., 1995; Janelle et al., 1997; Patterson & Carter, 2010; Patterson et al., in press), the use of physical assistive devices (Hartman, 2007; Wulf & Toole, 1999), the organization of practice repetitions (Keetch & Lee, 2007; Sanli & Patterson, 2009; Wu & Magill, 2004), and the frequency of observing a skilled model (Wrisberg & Pein, 2002; Wulf et al., 2005). Recently, the positive effects on motor learning associated with self-control have been demonstrated in children (Chiviacowsky et al., 2008a; Chiviacowsky et al., 2008b; Sanli & Patterson, 2009). The benefits of self-controlled practice includes discrete motor skills, for example underhand throws (Janelle et al., 1995; Janelle et al., 1997); serial tasks such as cursor aiming tasks (Keetch & Lee, 2007) and key pressing (Chiviacowsky & Wulf, 2002, 2005; Patterson & Carter, 2010; Patterson et al., in press); and continuous motor tasks like slalom ski

movements (Wulf & Toole, 1999). Although the superiority of a self-controlled practice environment is well documented for a variety of practice variables as well as different classifications of motor skills, a limiting factor in its generalizability is that these findings are limited to younger adults and more recently, children.

A population receiving only moderate attention in motor learning research is older adults. The results of these studies have revealed inconsistencies in the understanding of how older adults learn motor tasks (see Voelcker-Rehage, 2008 for a review) as two opposing notions have been generated: (1) that younger adults and older adults learn similarly (Carnahan et al., 1996; Jamieson & Rogers, 2000; Kausler, Wiley & Phillips, 1990; Swanson & Lee, 1992; van Dijk et al., 2007) or (2) that age-related differences in learning exist between younger and older adults (Tunney, Taylor, Gaddy, Rosenfeld, Pearce, Tamanini & Treby, 2003; van Hedel & Dietz, 2004; Voelcker-Rehage, Stronge & Alberts, 2006; Wishart et al., 2002).

The variability of a random practice schedule facilitated greater performance and learning in both younger and older adults for five different ATM transaction tasks compared to blocked practice (Jamieson & Rogers, 2000). Younger and older adults encoded contextual information similarly for learning and recalling 16 brief object manipulation actions (e.g., placing a cup onto a saucer) through distributed repetitions compared to massed repetitions (Kausler et al., 1990). Older adults also experienced similar learning to their younger adult counterparts for a four digit key pressing sequence when temporal KR was digitally displayed after every five trials (e.g., movement time for all five trials were displayed simultaneously) compared to after every trial (Carnahan et al., 1996). For learning a three segment barrier knock down task, a random KR schedule where KR about one of the three segments was randomly provided resulted in greater learning compared to a blocked KR schedule, where participants received KR about each of the segments for a predefined number of trials (e.g., trials one to 30 for segment one; trials 30 to 60

for segment two, etc.,) (Swanson & Lee, 1992). Kinetic feedback (e.g., overlaying the produced force onto the criterion waveform) promoted learning of an isometric force production task in younger and older adults compared to KR that was displayed as the average absolute error (van Dijk et al., 2007). It is believed by some that practice contexts utilizing KR facilitates equivalent learning of different motor skills in younger and older adults (Carnahan et al., 1996; Swanson & Lee, 1992; Wishart & Lee, 1997).

In contrast to the aforementioned studies, age-related differences in practice factors facilitating motor learning have been identified. For example, concurrent feedback proved to be more beneficial in learning a bimanual coordination pattern in older adults while younger adults benefited equally from a terminal or concurrent feedback schedule (Wishart et al., 2002). The bimanual coordination pattern required effortful processing and due to a slowing in information processing abilities with advancing age (Bäckman, Ginovart, Dixon, Wahlin, Wahlin, Halldin & Farde, 2000; Bäckman, Lindenberger, Li & Nyberg, 2010; Drag & Bieliauskas, 2010; Fjell & Walhoud, 2010; Luo & Craik, 2008; Salthouse, 1996), concurrent feedback was more beneficial for older adults because it requires less cognitive effort compared to a terminal feedback schedule. Cognitive load is decreased with concurrent feedback because participants can rely on the real time display of their movements to make online performance adjustments rather than having to interpret intrinsic sources of feedback such as proprioception for online corrections. Age-related differences emerged when learning to use a standard walker to get into the passenger side of a vehicle (Tunney et al., 2003). Participants viewed a live demonstration by the examiner prior to a single session of directed practice. Younger adults scored significantly higher on a 10 component measure of performance (e.g., step backwards with correct gait sequence) for both the final practice trial and the 48 hour retention test as measured by the examiner (Tunney et al., 2003). The number of movement components (10, each with subcomponents) for this task could

have caused the performance differences between the younger and older adults as a decreased working memory capacity is associated with increased age (Bäckman et al., 2000; Bäckman et al., 2010; Drag & Bieliauskas, 2010; Fjell & Walhoud, 2010; Luo & Craik, 2008; Salthouse, 1996). As a result, the number of movement components could have exceeded their working memory. Age-related differences were also documented when older adults exhibited a decrease in both cognitive (*n*-back test) and motor (force-tracking) performance under dual-task conditions whereas younger adults did not show decreases as task complexity increased (Voelcker-Rehage et al., 2006). The *n*-back test requires participants to repeat the *n*th item back from a list of items, such as 1-back or 2-back (Voelcker-Rehage et al., 2006). Similar to Wishart et al. (2002) and Tunney et al. (2003), Voelcker-Rehage et al. (2006) suggested that cognitive deficits were responsible for the older adults' poor performance under dual-task conditions. Interestingly, mixed results were found between younger and older adults in the acquisition and performance of a treadmill obstacle stepping task under full and restricted vision (van Hedel & Dietz, 2004). Under full vision, task accuracy increased with subsequent runs regardless of age; however, when vision was restricted, performance was negatively affected for both age groups but only the younger adults were capable of improving task accuracy (van Hedel & Dietz, 2004). This lead van Hedel & Dietz (2004) to conclude that older adults are less able to utilize proprioceptive feedback mechanisms to replace visual information compared to younger adults.

In summary, research examining age-related differences in the practice factors facilitating motor learning is rather ambiguous; and consequently fails to provide a comprehensive framework detailing the generalizability of learning advantages between younger and older adults.

Research providing older adults with the opportunity to control a portion of their practice environment is limited in motor learning. Therefore, it is not well understood if self-controlled

practice in older adults would yield the same learning advantages found in younger adults. A recent study examined the learning effects associated with older adults afforded the opportunity to individualize their KR schedule for a walking task that consisted of an overall timing goal and two segmental timing goals (Patterson et al., 2009). Patterson et al. (2009) found that the younger adults performed with greater timing accuracy compared to the older adults in acquisition, retention and transfer. The authors did not replicate the results of previous self-controlled KR schedules (Chiviakowsky & Wulf, 2002, 2005); however, it is believed that this was a function of how feedback was provided to the participants as evidenced by high KR requests in both younger (88.5% of trials) and older (92.5% of trials) adults. The feedback display required participants to extrapolate their actual KR scores that were presented as a percent for both segmental goals. For example, the first portion of the walking path was to be completed in 37.5% of the overall timing goal while the second portion was to be completed in 62.5%. Therefore, the increased cognitive load from this feedback schedule and the difficulties in translating the percentage timing scores from the KR display into meaningful information could have suppressed the previously found learning advantages of being able to individualize a KR schedule (Chiviakowsky & Wulf, 2002, 2005; Patterson & Carter, 2010; Patterson et al., in press).

Research in cognitive and verbal learning have revealed that when older adults are provided the choice to adopt a particular learning strategy (e.g., recognition/scanning or retrieval) they consistently adopt the least effortful strategy despite its diminished potential for learning in both the noun-pair lookup task (Hertzog et al., 2007; Rogers & Gilbert, 1997; Rogers et al., 2000; Touron & Hertzog, 2004) and for solving novel arithmetic problems (Touron et al., 2004). The noun-pair lookup task requires participants to determine if a target noun-pair matches a pair located in the lookup table by visually scanning the table (e.g., low cognitive effort) or by memory retrieval (e.g., high cognitive effort). The novel arithmetic problems required

participants to adopt either a computational or retrieval strategy to determine whether three numbers (presented as $A \# B = C$) conformed to the criterion formula $[(B - A) + 1] + B = C$. For both tasks, age-related differences in performance were related to the older adults' reluctance to use the retrieval strategy to make their responses. Interestingly, older adults remain biased towards adopting a strategy requiring low cognitive investment despite being aware of its diminished potential for learning. This is a particularly interesting finding as it provides insight into the preferred learning context of older adults compared to younger adults who consistently choose a retrieval strategy. This is consistent with the self-control literature in motor learning where younger adults intuitively increase their cognitive effort over practice (e.g., increasing the number of no-KR trials) (Chiviackowsky & Wulf, 2002; 2005). Moreover, this bias towards a practice environment with low cognitive demands in the verbal learning domain could be correlated to earlier age-related research identifying a slowing in information processing abilities and a decreased working memory capacity (Bäckman et al., 2000; Bäckman et al., 2010; Drag & Bieliauskas, 2010; Fjell & Walhoud, 2010; Luo & Craik, 2008; Salthouse, 1996). Perhaps this strategic preference of the older adult exists because they are cognizant of these age-related changes, and in an effort to avoid further taxing their already compromised information processing system, they opt for a less than optimal learning strategy.

Previous research examining age-related differences in motor skill learning have identified conflicting results where older adults have learned (Carnahan et al., 1996; Jamieson & Rogers, 2000; Kausler et al., 1990; Swanson & Lee, 1992; van Dijk et al., 2007) and not learned (Tunney et al., 2003; van Hedel & Dietz, 2004; Voelcker-Rehage et al., 2006; Wishart et al., 2002) new motor skills through the same experimental manipulations as younger adults. Consequently, there are numerous age-related variables that must be addressed when creating an optimal learning environment for the older adult; therefore, providing older adults with the

opportunity to individualize their practice environment for learning a motor task should allow the older adults to structure their practice to maximize their information processing potential and subsequent learning.

2.2 Statement of the problem

The urgency in understanding the practice factors facilitating motor learning in older adults is based on the fact the population of older adults (≥ 60 years) is increasing more rapidly than all other age groups (Health Canada, 2002). In fact, it is expected that over the next three decades, the older adult population will account for half of the overall Canadian population growth (Health Canada, 2002). In addition, Health Canada (2002) has estimated that by 2021, there will be 6.7 million older adults and by 2041 this number will increase to 9.2 million. Therefore, motor learning research involving older adults is crucial based on current and future demands for researchers and practitioners to understand the practice factors facilitating motor skill acquisition for this population. A better understanding of how older adults learn will promote increases in quality of life through the creation of more effective rehabilitation programs, vocational training, and recreational outlets.

Based on a limited body of research affording older adults the opportunity to individualize a portion of their practice context, it is currently not understood if the learning advantages associated with self-controlled practice in younger adults would also be experienced by older adults. Previous research has revealed age related changes in the cognitive (e.g., information processing and working memory capacity) (Bäckman et al., 2000; Bäckman et al., 2010; Drag & Bieliauskas, 2010; Fjell & Walhoud, 2010; Luo & Craik, 2008; Salthouse, 1996) and sensorimotor processes (Adamo, Martin & Brown, 2007; Meeuwsen, Sawicki & Stelmach, 1993; Seidler, 2006; Seidler & Stelmach, 1995) with advancing age. These identified age-related

changes have resulted in increased movement time (Shea, Park & Braden, 2006; Welsh, Higgins & Elliot, 2007), increased response time (Jamieson & Rogers, 2000; Roy, Weir, Desjardins-Denault & Winchester, 1999; Yan, Thomas & Stelmach, 1998), increased movement variability (Enoka, Christou, Hunter, Kornatz, Semmler, Taylor & Tracey, 2003; Sosnoff & Newell, 2006; Wiegand & Ramella, 1983), and an increase in errors (Jamieson & Rogers, 2000; Swanson & Lee, 1992; Tunney et al., 2003; Wishart & Lee, 1997). Therefore, it would be expected that providing older adults with the opportunity to control a portion of their practice environment is an opportunity to compensate for these age related changes.

Self-control has unequivocally facilitated the learning of motor tasks in younger adults and children; however, the exact mechanisms responsible for the learning advantages of a self-controlled practice environment are speculative. Currently, researchers have speculated that a self-controlled practice environment facilitates the participant's engagement in the learning process; thus, increasing intrinsic motivation (Boekaerts, 1996; Chiviacowsky & Wulf, 2002; 2005; Winne, 1995; Wulf, 2007); that the practice conditions are more individualized (Chen et al., 2002; Chiviacowsky & Wulf, 2002; Keetch & Lee, 2007); and task information is believed to be processed in a more meaningful way (Boekaerts & Corno, 2005; Chiviacowsky & Wulf, 2002; Wulf, 2007). However, attempts to capture the different brain structures that are activated or the degree of activation during self-controlled practice compared to non-control yoked practice is non-existent. Until these methodological limitations are resolved, the mechanisms responsible for learning in self-controlled practice environments will remain speculative. In contrast, what is well understood in self-controlled practice for motor skill learning is that when participants are provided the opportunity to control a specific practice variable, they appear to adopt a specific strategy. For example, participants requested balance poles for balancing on a stabilometer when attempting a new performance strategy (Hartman, 2007). Also, when participants controlled their

receipt of KR, the majority of participants preferred to receive KR *after perceived good trials* (Chiviakowsky & Wulf, 2002; Patterson & Carter, 2010; Patterson et al., in press). Interestingly, this preference for KR challenges previous notions on the role of KR to resolve differences between the actual and the desired performance (Adams, 1971; Schmidt, 1975). Furthermore, these self-reported strategies have, in some cases, corresponded to the actual behavioural measures of participants, with greater accuracy on KR trials compared to no-KR trials (Chiviakowsky & Wulf, 2002). However, what remains unknown are the specific sources of information the participants are interpreting to determine whether a trial was *good* or *bad*. Therefore, future studies are required to examine the specific roles that motivation and intrinsic feedback have in producing the learning advantages of a self-controlled practice context.

Proprioception may have a significant role in the strategies adopted by participants in a self-controlled practice context as previous studies have revealed that participants typically decrease their use of the practice variable being controlled as practice progresses (Janelle et al., 1995; Janelle et al., 1997; Wulf et al., 2005; Wulf & Toole, 1999). For example, Janelle et al. (1995) found that participants systematically decreased their reliance on KR during acquisition and only requested feedback on 7% of acquisition trials while participants in Janelle et al. (1997) decreased their receipt of KR from 9.1% of the time in block one to 2.9% by block 20. Wulf et al. (2005) also reported that participants decreased their need for a model demonstration throughout acquisition and only requested a model demonstration on 5.8% of the practice trials. Wulf & Toole (1999) found that during practice on day one, participants requested the use of the ski poles for 92% of the time on trial one and gradually reduced it to 54% by the last trial. A similar decrease was noted on day two of practice with ski poles being requested for 85% of the time on trial one and only 25% of the time by the last trial. Therefore, it appears that external support during practice is systematically being replaced by an increased reliance on a reference of

correctness for the motor skill. In general, more specific measures tailored to motivation, intrinsic feedback or information processing need to be included in future studies to better understand the exact mechanisms responsible for the powerful learning advantages that have been demonstrated when participants practice in a self-controlled environment.

The purpose of this thesis was two-fold. First, to examine the utility of a self-controlled KR schedule during the acquisition of a spatial motor task in younger and older adults and second, to determine whether a self-controlled KR schedule facilitates an increased ability to estimate one's performance in retention and transfer. Of secondary interest was to determine if participants' preferences for requesting KR would change as a function of the number of practice trials completed and age.

2.3 Experimental predictions

Based on the existing literature, the following predictions were made:

1. Irrespective of age, the SELF conditions would perform more accurately (e.g., less $|CE|$) in retention (Chen et al., 2002; Patterson & Carter, 2010; Patterson et al., in press) and in transfer (Chiviacowsky & Wulf, 2002; 2005) compared to their YOKED counterparts
2. Participants in the SELF conditions would be more accurate in estimating their performance in retention and transfer compared to the YOKED conditions. This prediction is based on previous research revealing a decreased reliance on the practice variable being controlled during acquisition (Janelle et al., 1995; Janelle et al., 1997; Wulf et al., 2005; Wulf & Toole, 1999).
3. Participants in the SELF-OLD condition would bias towards less effortful KR schedules (e.g., high frequency of KR requests) compared to the SELF-YOUNG condition based on findings from the cognitive learning literature where older adults consistently self-select the less effortful

learning strategy (Hertzog et al., 2007; Rogers et al., 2000; Touron et al., 2004; Touron & Hertzog, 2004).

4. Irrespective of KR condition, younger adults would perform more accurately (e.g., less $|CE|$) and more consistently (e.g., less VE) than the older adults in all experimental phases (Carnahan et al., 1996; Enoka et al., 2003; Sosnoff & Newell, 2006; Swanson & Lee, 1992; Wiegand & Ramella, 1983; Wishart & Lee, 1997; Wishart et al., 2002)

CHAPTER 3: METHODOLOGY

3.1 Participants

Twenty younger adults (self-control condition, M age = 22, SD = 1.15; yoked condition, M age = 22.7, SD = 0.95) and 20 older adults (self-control condition, M age = 69.9, SD = 6.05; yoked condition, M age = 69.2; SD = 6.11) participated in the experiment. The younger adults were recruited from the undergraduate and graduate population at Brock University while the older adults were recruited from the community of St. Catharines and surrounding areas. Participants were assigned to practice in either the SELF-YOUNG (n = 10), the SELF-OLD (n = 10), the YOKED-YOUNG (n = 10), or the YOKED-OLD (n = 10) condition. All conditions comprised 5 males and 5 females. The first 10 younger adults and 10 older adults were assigned to their respective self-control condition while the remaining younger and older adult participants were assigned to their respective age-matched yoked condition. Measures of cognitive functioning and functional independence were collected for all participants using the Mini Mental State Exam (see Appendix A) and the Barthel Index (see Appendix B), respectively. Mean scores for these tests are presented in Table 1. All participants scored at or above the required levels to be included in the experiment. All participants self-reported the absence of any musculoskeletal or neurological problems that would have limited their participation in the experiment. All participants signed an informed consent that had been approved by the Brock University Research Ethics Board and were naïve to the purposes of the experiment.

Table 1

Mean participant scores with standard deviation on Barthel Index and Mini Mental State Exam as a function of KR condition and age

Inclusion test	Self-control conditions		Yoked conditions	
	Younger adults	Older adults	Younger adults	Older adults
Barthel Index	$M = 100, SD = 0$	$M = 100, SD = 0$	$M = 100, SD = 0$	$M = 100, SD = 0$
MMSE	$M = 30, SD = 0$	$M = 29.3, SD = 0.67$	$M = 30, SD = 0$	$M = 100, SD = 0.99$

Note. The Barthel Index is a measure of functional independence. Scores on this test can range from 0 to 100 with 100 designating functional independence. The MMSE (Folstein, Folstein & McHugh, 1975) is a measure of cognitive functioning. Scores on this test can range from 0 to 30 with scores ≥ 24 indicating an individual is free of any cognitive impairment.

3.2 Apparatus

Throughout the acquisition, retention and transfer periods of the experiment, participants were seated behind the home position of the apparatus (see Appendix C). The home position refers to the location on the apparatus where the slide rested at the beginning of each trial. The apparatus was secured to a table that was 243.8 cm (length) by 50.2 cm (width) by 60.3 cm (height). The total length of the apparatus railing was 261.6 cm with the railing located 30.5 cm above the table surface. The railing was divided into two separate areas: a warm-up area, where participants could move the slide back and forth before releasing it and the scoring area. The slide was 12.1 cm (length) by 17.1 cm (height), weighed 455g and had a large knob for the participants to grip. The two areas were divided by a wooden barrier that was located 50 cm from the home position, termed the release line. The wooden barrier was 78.7 cm (height) by 45.7 cm (wide) and had an opening equal to the size of the slide. The wooden barrier prevented the participants from viewing the scoring zone and final resting place of the slide. At the end of the apparatus railing,

opposite to the home position, a Vernier Motion Detector (see Appendix D) was positioned on a customized mount. The motion detector functioned at an ultrasound frequency of 50 kHz with an accuracy of 2 mm within a range of 0.5 to 6 m. The motion detector was connected to the BTD port on the Vernier LabPro (see Appendix E). The LabPro is an instrument for data collection and was connected to the serial port of a computer. The LabPro was 21.5 cm (length) by 8.2 cm (width) by 3 cm (height). The LabPro received commands from the computer to activate the motion detector and to transmit the motion detector's reading on each trial to the customized software program installed on the computer.

It was important to ensure that the relative friction of the apparatus did not change throughout testing because this would confound our results. Therefore, to determine that the relative friction did not change throughout testing, a pulley-system was constructed and attached to the apparatus. The pulley-system consisted of a cable wire (215 cm) that was attached to a weight (505 g) at one end. At the opposite end, the cable wire was attached to a fishing clip that could be clipped to the slide when relative friction was assessed. The weight attached to the pulley-system ensured the same amount of force was always used to move the slide along the apparatus railing. The motion detector was determined the distance the slide travelled and the value was recorded in the customized software program. The results of the friction testing can be found in Appendix F.

3.3 Experimental task

The experimental task was a modification of a linear slide task but required participants to push and release a slide along a confined pathway to a pre-determined distance (133 cm) as accurately as possible. Participants used their non-dominant hand to perform the task as a method of increasing the novelty and complexity of the task. Similar to numerous real-life motor tasks

such as picking up a cup, curling and billiards, participants needed to accurately calibrate their force through their interpretation of intrinsic feedback to successfully perform the task. Participants were required to wear a pair of Mastercraft Standard Earmuffs to eliminate auditory feedback from the apparatus. The travel pathway was occluded from the release point and on by a wooden barrier to eliminate visual feedback. The elimination of auditory and visual information, previously shown to be important to learning (e.g., recognition schema from Schmidt, 1975) allowed us to examine the role of proprioception in a self-controlled KR schedule. Thus, the ability of participants, as a function of their KR condition and age, to use proprioceptive feedback (e.g., information from proprioceptors – muscle spindles, Golgi tendon organs and joint receptors) for performance estimations was investigated. This is important because intrinsic or response produced feedback is naturally available when a movement is made (Salmoni et al., 1984). Therefore, the successful interpretation of intrinsic feedback is critical to the development of a reference of correctness (Schmidt & White, 1972) since augmented feedback may not always be available to the learner (e.g., in a game situation or no-KR retention tests). The goal of the task for all participants was to push and release the slide along the confined pathway to the goal distance as accurately as possible. The task goal was the same for the acquisition and retention trials; however, for the transfer test a novel goal distance (165 cm) was used.

3.4 Procedure

Upon arrival to the lab, each participant was administered the MMSE to screen for any cognitive impairments, and the Barthel Index to assess their functional status (see Table 1). Both are self-report scales. The MMSE was used as an inclusion criterion for the experiment, consistent with previous studies involving older adults (Maryott & Sekuler, 2009; Seidler, 2006; Swanson & Lee, 1992). The MMSE assesses various cognitive functions (e.g., arithmetic and memory) which are critical to understanding the experimental instructions and interpreting the

feedback display on KR trials. According to the MMSE, a score of ≥ 24 out of 30 points is needed to be considered free of cognitive impairment. As a result, all participants were required to score between 24 and 30 points. The Barthel Index required participants to self-report their ability to complete several typical daily tasks (e.g., feeding, dressing and mobility). All participants needed to report a comparable level of functional ability. The pre-testing was important for this study because it involved a heterogeneous group of participants; therefore, any potential age-related differences in performance and learning would not be attributed to initial differences in cognitive and/or functional abilities.

Prior to the testing phase, participants were required to read through a series of instruction slides presented in Microsoft PowerPoint outlining the task, the task goal and when KR for their respective experimental condition would be provided. Importantly, each instruction slide was presented for as long as the participant needed in order to ensure the experimental protocol was understood. Furthermore, participants were allowed to ask any questions regarding the instructions if clarification was required.

The instructions for the experimental protocol were equated across all experimental conditions; however, the instructions pertaining to KR presentation were specific to experimental condition. Participants in the self-control conditions were informed that upon completion of every trial, they would be prompted to orally inform the researcher whether they wanted to receive or not receive KR. Importantly, the participants were informed to only request KR when necessary because there would be a time in the experiment when KR would not be made available. The participants in the yoked conditions were informed that upon completion of every trial, they may or may not receive KR. After the instruction slides, all participants performed two practice trials in their respective experimental conditions to familiarize themselves with the task. Importantly, the goal distance used in the familiarization trials was different from the goal distances used in

the experimental phases. Furthermore, the familiarization trials ensured all participants were able to interpret the KR presentation correctly because all participants were asked to orally state their interpretation of the KR display to the researcher. If needed, the researcher clarified any discrepancies in the interpretation of the KR display.

All participants completed 60 acquisition trials. A typical experimental trial began with the participant sitting behind the home position of the apparatus with their non-dominant hand resting on the slide. Participants had 5000 ms to push and release the slide which was indicated by a green light displayed on a computer monitor. Before the light turned green, a red light was visible to the participants on the computer monitor and signified the trial had yet to begin. The pathway that the slide travelled along was occluded by a wooden barrier from the release line on. The distance from the home position to the release line was 50 cm. Participants in the self-control conditions were prompted to decide after each trial whether they wanted to receive or not receive KR regarding their just completed response. If the participant indicated yes to the researcher, KR was presented and consisted of the goal distance (cm), their distance (cm), and the difference between the goal distance and their response. The direction of their error relative to the task goal was indicated by either a minus (-) or a plus (+) sign in front of x cm (e.g., -5 cm would indicate too short by 5 cm). The difference between the goal distance and their performance was provided to ensure that KR would not be misinterpreted from subjective errors in mathematical calculations. The KR display was presented for 5000 ms. If the participant indicated that KR was not wanted, a blank screen was displayed for 5000 ms before the next trial began in order to maintain a consistent inter-trial interval. Participants in the yoked conditions received an identical KR schedule to an age and gender matched self-control participant, however without the choice of when KR was provided. Therefore, for the yoked conditions, the customized computer

program automatically initiated the feedback display on a KR trial or a blank screen on a no-KR trial for 5000 ms.

Following the acquisition period, all participants were asked to complete a multiple choice KR questionnaire (Chiviacowsky & Wulf, 2002) (see Appendixes G1 & G2). Participants in the self-control conditions were required to answer questions to determine their KR preferences for the first half of practice (blocks 1 to 5) separate from the second half of practice (blocks 6 to 10) to determine whether KR preferences changed as a function of the number of acquisition trials completed. In contrast, participants in the yoked conditions were asked to introspect on whether they received KR after the right trials and if not, when they would have preferred to receive KR. In order to provide a period of no practice prior to the immediate retention test, all participants sat at a desk stationed away from the apparatus in the lab and completed a word search for 10 minutes.

To assess learning, all participants completed an immediate (10 minute) and delayed (24 hour) retention test that consisted of 10 no-KR trials. To determine whether the ability to accurately estimate one's performance was an inherent product of a self-controlled KR schedule, all participants were asked to estimate the distance (e.g., how far do you think you projected the slide?) of their response for each retention trial, similar to the judgments of learning (JOLs) in Simon & Bjork (2001). Upon completion of each retention trial, participants waited 5000 ms prior to writing their performance estimation on a designated cue card.

To assess the ability of the participants, as a function of age and KR condition, to generalize their motor learning to a novel task parameter, all participants were required to complete a transfer test consisting of 10 no-KR trials involving a novel goal distance. Similar to a retention test, a transfer test is important to motor learning because it offers another way to

measure mastery of a task in the absence of any potential temporary effects of performance variables. The transfer test was completed following the delayed retention test on day two. The experimental protocol for the retention tests was repeated in the transfer test. We assessed performance estimations of participants only in retention because if performance estimations were made during practice, this would have confounded the results of the experiment since it would be problematic to determine which practice manipulation, self-control or estimating one's performance was responsible for facilitating motor learning. After the transfer test, participants were presented with a two-part questionnaire regarding intrinsic feedback sources, similar to that used by Anderson, Magill, Sekiya & Ryan (2005) (see Appendix H). Participants completed the questionnaire at a table in the lab that was located away from the apparatus. Specifically, the first part required participants to indicate whether they utilized any other sources of information in addition to KR or when KR was not available during practice and, if so, to self-report all sources of intrinsic feedback they may have used (e.g., hand position, wrist position, shoulder position, produced force, etc.). Second, participants were asked to indicate whether the sources they used changed with practice and, if so, to briefly describe the nature of the change. This questionnaire took approximately five minutes to complete.

It is important to note the timing of this questionnaire was identical to that of Anderson et al. (2005). If participants had completed the questionnaire regarding intrinsic feedback sources at the end of the acquisition phase, this would have been a serious threat to internal validity since it could have cued the participants' attention to particular intrinsic feedback sources for the retention and transfer tests. Therefore, to avoid violating internal validity, the intrinsic feedback questionnaire was administered after all experimental testing was completed.

During the acquisition, retention and transfer periods of the experiment, absolute constant error ($|CE|$) and variable error (VE) were calculated. $|CE|$ is a measure of performance accuracy

and is defined as the absolute mean deviation from the goal distance (cm) and the participant's distance (cm) (Schmidt & Lee, 2005). VE is an index of performance consistency and is defined as the standard deviation of a block of scores in reference to the participant's average score (Schmidt & Lee, 2005). It was believed that these measures would best represent motor learning in the experiment, as well as these measures were used in previous research examining self-controlled KR schedules and motor tasks requiring accuracy (Chen et al., 2002; Chiviacowsky & Wulf, 2005; Patterson & Carter, 2010; Patterson et al., in press).

3.5 Data analysis

For the acquisition phase, the means for |CE| and VE were grouped into 10 blocks of six trials. The dependent variables of |CE| and VE were analyzed in separate 2 (age: young, old) x 2 (practice condition: self, yoked) x 10 (block) analysis of variance (ANOVA) with repeated measures on the last factor.

For the retention and transfer periods, |CE| and VE were collapsed into one block of 10 trials. For the retention tests, the dependent variables were analyzed in separate 2 (age: young, old) x 2 (practice condition: self, yoked) x 2 (retention test: immediate, delayed) ANOVA with repeated measures on the last factor. For the transfer test, mean |CE| and VE were submitted to separate 2 (age: young, old) x 2 (practice condition: self, yoked) ANOVAs. To assess the accuracy of the participants' performance estimations in retention and transfer as a function of age and KR condition, the mean absolute difference (AD) between actual performance and estimated performance was calculated, similar to the participants' performance predictions (indexed by %JOL) in Simon & Bjork (2001). The AD data for retention was submitted to a 2 (age: young, old) x 2 (practice condition: self, yoked) x 2 (retention test: immediate, delayed)

ANOVA with repeated measures on the last factor. The AD data for transfer was submitted to a 2 (age: young, old) x 2 (practice condition: self, yoked) ANOVA.

All statistical analyses were conducted using Statistica version 7.0 by StatSoft Inc. A significance level of $p \leq .05$ was used for all statistical analyses and any motor performance measures (e.g., |CE|, VE) that were greater than two standard deviations from the mean were defined as statistical outliers and were removed from further analysis. Furthermore, any statistically significant interactions were analyzed using the Tukey's HSD post hoc analysis.

CHAPTER 4: RESULTS

4.1. Knowledge of results (KR) requests during acquisition

The proportions of requested KR trials during the acquisition period are displayed in Figure 1. During the acquisition period (blocks 1-10), participants in the SELF-YOUNG condition requested KR on 69.8%, 73.1%, 54.8%, 68.2%, 59.8%, 61.4%, 59.7%, 68.1%, 73.2%, and 57.9% of the acquisition trials. The participants in the SELF-OLD condition requested KR on 76.5%, 80%, 69.8%, 68.2%, 71.6%, 68.3%, 71.5%, 68.3%, 88.3%, and 78.3% of the acquisition trials. Overall, the SELF-YOUNG condition requested KR on 64.6% ($SD = 27\%$) of the acquisition trials whereas the SELF-OLD condition requested KR on 74.1% ($SD = 35\%$) of the acquisition trials. The ANOVA did not reveal a main effect for age, $F(1, 18) = .46, p > .05$; block, $F(9, 162) = 1.53, p > .05$, or an age x block interaction, $F(9, 162) = .49, p > .05$.

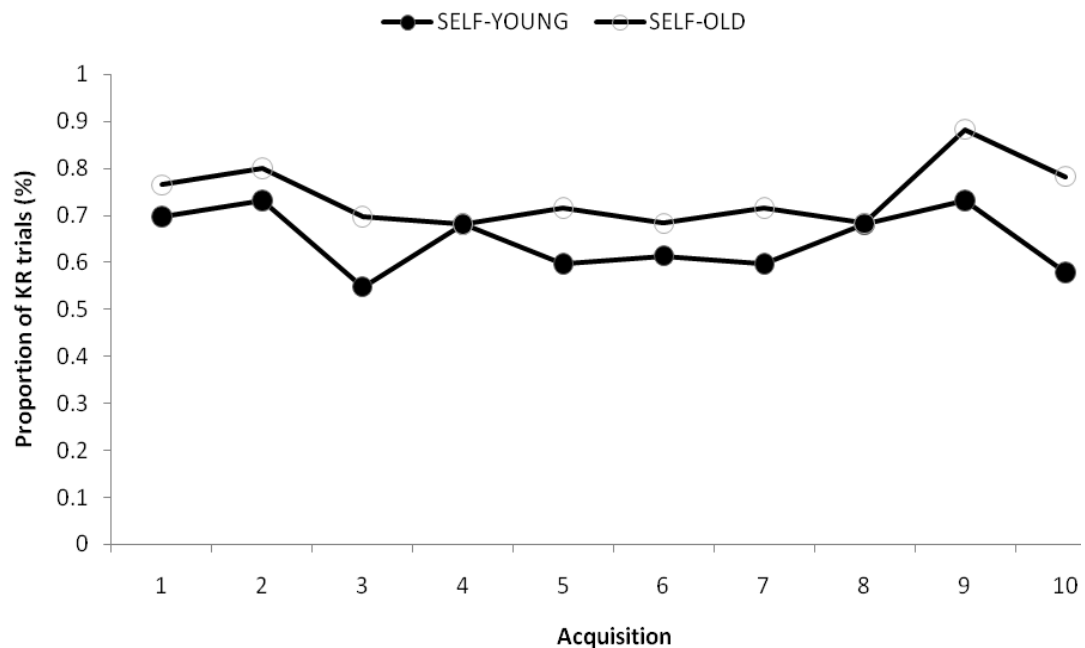


Figure 1. The proportions of requested KR trials during acquisition by the self-control conditions as a function of age.

4.2. Absolute constant error (|CE|)

4.2.1. Acquisition

The means for |CE| for all experimental conditions are displayed on the left panel of Figure 2. There was a significant main effect for KR condition, $F(1, 29) = 14.70, p \leq .05$ with the SELF conditions ($M = 20.76, SD = 7.92$) demonstrating less |CE| than the YOKED conditions ($M = 23.19, SD = 5.95$). The main effect for age, $F(1, 29) = 59.76, p \leq .05$, was also statistically significant where the younger adults ($M = 18.13, SD = 5.43$) performed with less |CE| than the older adults ($M = 25.82, SD = 6.37$). There was also a significant main effect for block, $F(9, 261) = 14.76, p \leq .05$. The post hoc analysis indicated that block 1 was performed with more |CE| than blocks 2 to 10; block 2 was performed with more |CE| than blocks 6, 9 and 10; and blocks 3 and 4 were both performed with more |CE| than blocks 9 and 10. The KR condition x age interaction, $F(1, 29) = 3.27, p > .05$; the block x KR condition interaction, $F(9, 261) = 1.80, p > .05$; the block x age interaction, $F(9, 261) = .25, p > .05$; and the block x KR condition x age interaction, $F(9, 261) = .80, p > .05$, were not statistically significant.

4.2.2. Retention

The means for |CE| for all experimental conditions are displayed on the middle panel of Figure 2. There was a significant main effect for retention test, $F(1, 34) = 7.73, p \leq .05$, where the immediate retention test (10-minute) was performed with less |CE| than the delayed retention test (24-hours). The main effects for KR condition and age were superseded by a KR condition x age interaction, $F(1, 34) = 4.57, p \leq .05$. The post hoc test indicated that the SELF-YOUNG group performed with less |CE| than all other experimental conditions. The retention test x KR condition interaction, $F(1, 34) = .00, p > .05$; the retention test x age interaction, $F(1, 34) = .96, p > .05$; and

the retention test x KR condition x age interaction, $F(1, 34) = 1.88, p > .05$, were not statistically significant.

4.2.3. Transfer

The means for $|CE|$ for all experimental conditions are displayed on the right panel of Figure 2. The main effect for age, $F(1, 33) = 20.11, p < .05$, was statistically significant where the younger adults performed with less $|CE|$ than the older adults in the transfer test. The main effect for KR condition, $F(1, 33) = .13, p > .05$, and the KR condition x age interaction, $F(1, 33) = .00, p > .05$, were not statistically significant.

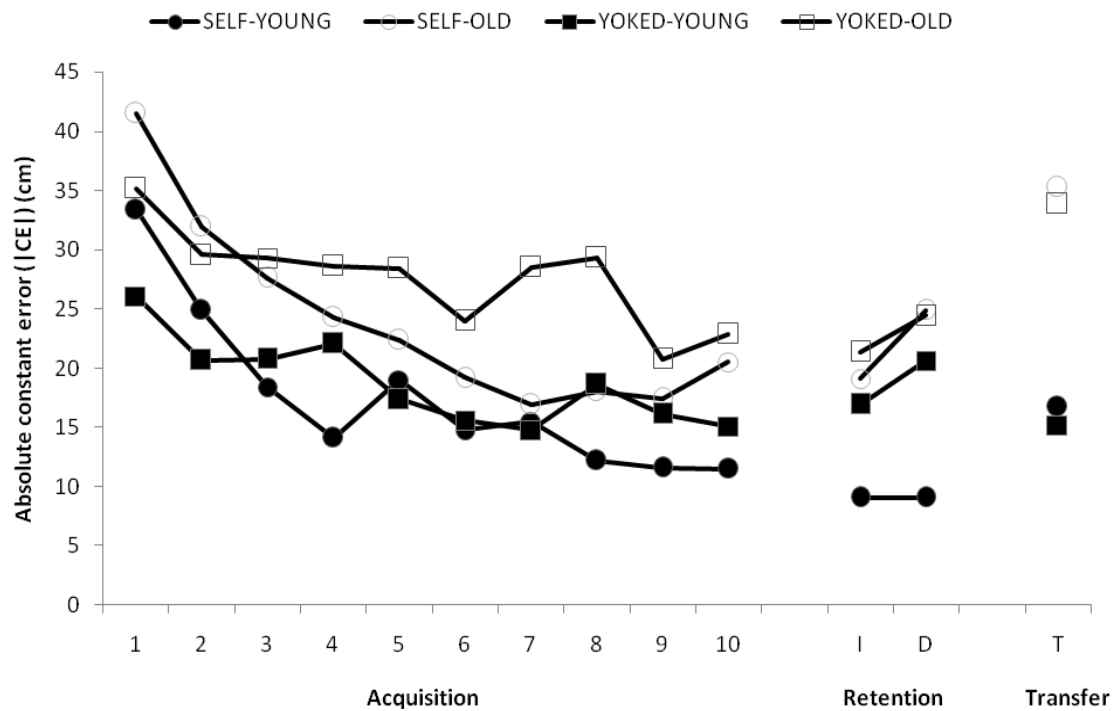


Figure 2. Absolute constant error ($|CE|$) for all experimental conditions for the acquisition (blocks 1 to 10), retention (immediate [10-min] and delayed [24-hr]), and transfer periods of the experiment.

4.3. Variable error (VE)

4.3.1. Acquisition

The means for VE for all experimental conditions are displayed on the left panel of Figure 3. There was a significant KR condition x age interaction, $F(1, 28) = 4.26, p \leq .05$ and a significant block x KR condition interaction, $F(9, 252) = 3.77, p \leq .05$. The post hoc analysis of the KR condition x age interaction indicated that the YOKED-OLD condition was more variable than all other conditions. The post hoc analysis of the block x KR condition interaction indicated differences within the experimental conditions only. In the SELF conditions, block 1 was more variable than blocks 2 to 10; block 2 was more variable than blocks 7 and 9; and block 4 was more variable than block 7. In the YOKED conditions, block 1 and block 3 were both more variable than block 10. The block x age interaction, $F(9, 252) = 1.44, p > .05$; and block x KR condition x age interaction, $F(9, 252) = .74, p > .05$, were not statistically significant.

4.3.2. Retention

The means for VE for all experimental conditions are displayed on the middle panel of Figure 3. The main effect for retention test, $F(1, 35) = 2.54, p > .05$, was not statistically significant. The main effects for KR condition and age were superseded by a KR condition x age interaction, $F(1, 35) = 12.02, p \leq .05$. The post hoc analysis indicated the SELF-YOUNG condition was less variable than all other conditions. The retention test x KR condition interaction, $F(1, 35) = .06, p > .05$; the retention test x age, $F(1, 35) = .76, p > .05$; and the retention test x KR condition x age interaction, $F(1, 35) = .35, p > .05$, were not statistically significant.

4.3.3. Transfer

The means for VE for all experimental conditions are displayed on the right panel of Figure 3. The main effect for age, $F(1, 32) = 1.78, p > .05$; and KR condition, $F(1, 32) = .32, p > .05$, were not statistically significant. The KR condition x age interaction, $F(1, 32) = .05, p > .05$, was also not statistically significant.

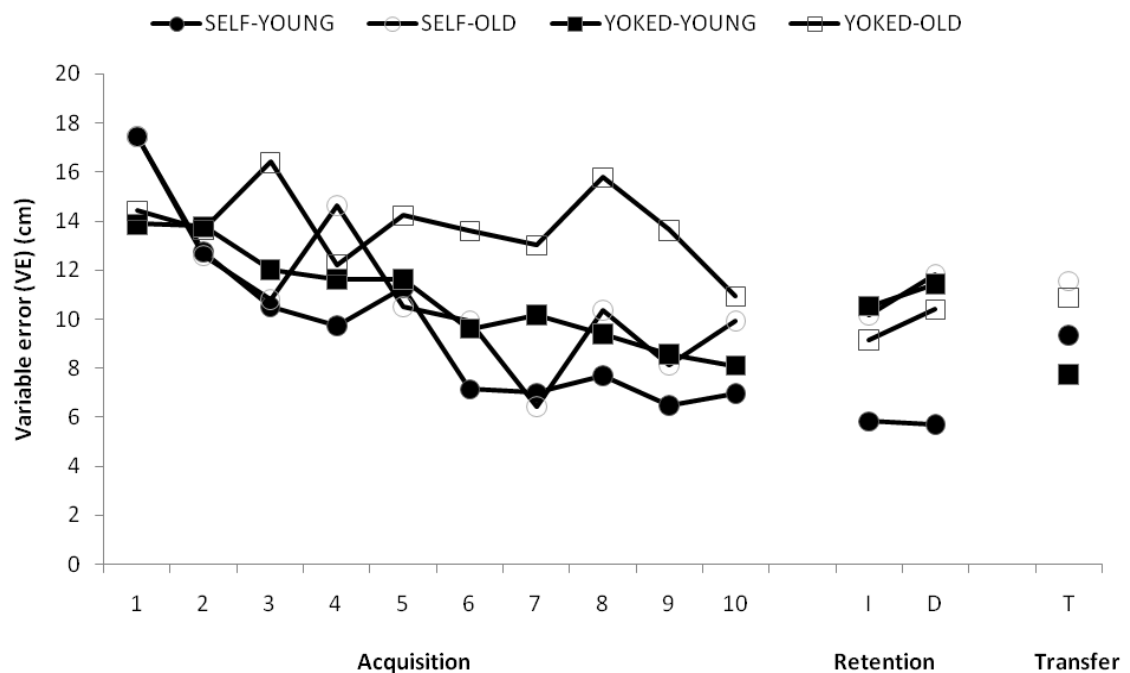


Figure 3. Variable error (VE) for all experimental conditions for the acquisition (blocks 1 to 10), retention (immediate [10-min] and delayed [24-hr]), and transfer periods of the experiment.

4.4. Absolute difference (AD)

4.4.1. Retention

The means for AD for all experimental conditions are displayed on the left panel of Figure 4. The main effect for retention test, $F(1, 34) = 2.53, p > .05$ was not statistically

significant. The main effects for KR condition and age were superseded by a KR condition x age interaction, $F(1, 34) = 4.51, p \leq .05$. The post hoc test indicated the SELF-YOUNG condition was more accurate at estimating their motor performance than all the other conditions. The retention test x KR condition interaction, $F(1, 34) = .01, p > .05$; the retention test x age interaction, $F(1, 34) = .02, p > .05$; and the retention test x KR condition x age interaction, $F(1, 34) = .05, p > .05$, were not statistically significant.

4.4.2. Transfer

The means for AD for all experimental conditions are displayed on the right panel of Figure 4. The main effect for age, $F(1, 34) = 20.88, p < .05$, was statistically significant with the younger adults being more accurate in estimating their motor performance during the transfer test compared to the older adults. The main effect for KR condition, $F(1, 34) = .08, p > .05$, and the KR condition x age interaction, $F(1, 34) = .35, p > .05$, were not statistically significant.

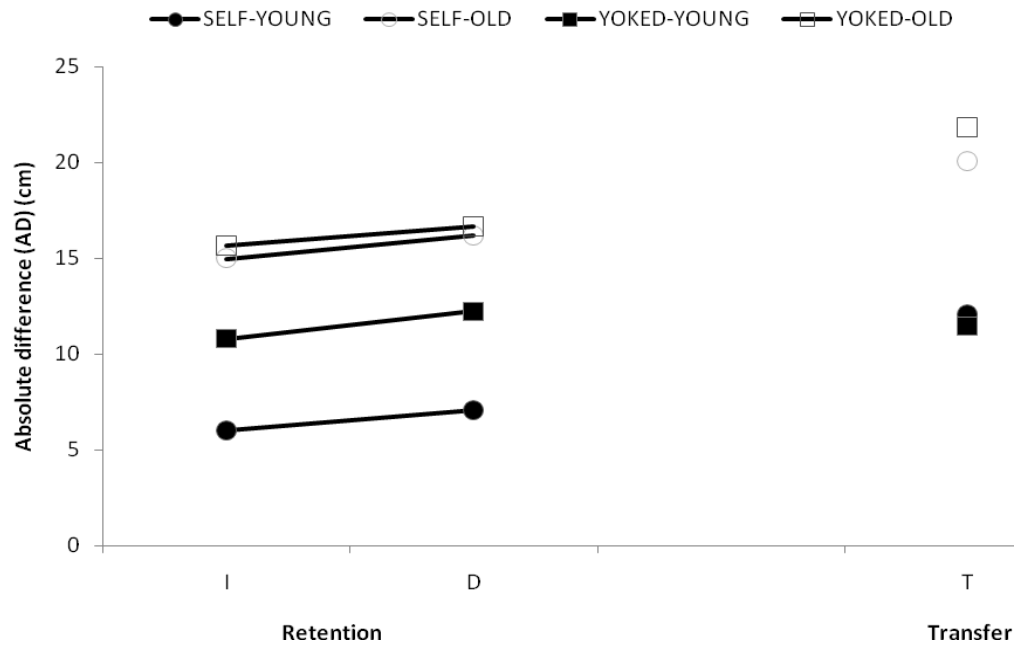


Figure 4. Absolute difference (AD) between the actual performance and the performance estimation for all experimental conditions for the retention (immediate [10-min] and delayed [24-hr]) and transfer periods of the experiment.

4.5. Self-reported KR scheduling strategy as a function of age and practice

The purpose of the self-reported KR preferences questionnaire in the present experiment was to determine whether age and the number of practice trials completed would differentially impact the individualization of KR requests. To examine this, the questionnaire created by Chiviawsky & Wulf (2002) was modified to have participants report their preference for KR for trials one to 30 (hereafter defined as the first half of practice) separate from trials 31-60 (hereafter defined as the second half of practice). The complete results of the questionnaire are displayed in Table 2. The important information from this data is highlighted below.

Table 2

Self-reported KR preferences of self and yoked participants during acquisition

KR condition	Younger adults	Older adults
Self-control condition	Number of responses	
1. <i>When/why did you ask for KR during the first half of practice?</i>		
a) mostly after a perceived good trial	4	3
b) mostly after a perceived bad trial	0	0
c) after perceived good and bad trials equally	6	5
d) randomly	0	0
e) other	0	2
2. <i>When/why did you ask for KR during the second half of practice?</i>	8	2
a) mostly after a perceived good trial	0	0
b) mostly after a perceived bad trial	2	5
c) after perceived good and bad trials equally	0	1
d) randomly	0	2
e) other		
3. <i>When did you not ask for KR during practice?</i>	0	0
a) mostly after a perceived good trial	9	3
b) mostly after a perceived bad trial	0	1
c) after perceived good and bad trials equally	0	1
d) randomly	1	5
e) other		
Yoked condition	Number of responses	
1. <i>Do you think you received KR after the right trials?</i>		
a) Yes	5	7
b) No	5	3
2. <i>If the answer to the above question was NO, when would you have preferred to receive KR?</i>		
a) mostly after a perceived good trial	5	0
b) mostly after a perceived bad trial	0	0
c) after perceived good and bad trials equally	0	3
d) randomly	0	0
e) other	0	0

Note. This KR preference questionnaire was modified for this experiment based on the original questionnaire created by Chiviacowsky & Wulf (2002).

During the first half of acquisition, 60% of participants in the SELF-YOUNG condition requested KR after *perceived good and bad trials* equally, while the remaining 40% requested KR after *perceived good trials* only. The preference for KR identified in the first half of practice switched during the second half as 80% of the SELF-YOUNG participants requested KR after *perceived good trials* only, and the remaining 20% requested KR after *perceived good and bad trials* equally. When participants were asked to report when they did *not* ask for KR, 90% of the SELF-YOUNG participants selected after *perceived bad trials* only, and 10% adopted a strategy not listed on the questionnaire (e.g., “I asked for feedback after every trial”). Similar to the SELF-YOUNG condition, the SELF-OLD condition reported a preference for KR after *perceived good and bad trials* during the first half of acquisition with 50% of participants reporting this strategy. Thirty percent of participants requested KR after *perceived good trials* only, and 20% of participants requested KR through a strategy not listed on the questionnaire (e.g., “I wanted feedback all the time” and “always asked for feedback”). In contrast to the SELF-YOUNG condition, the preference for KR reported for the second half of the acquisition period remained the same in the SELF-OLD condition with 50% of participants requesting KR after *perceived good and bad trials* equally. Twenty percent of participants requested KR after *perceived good trials* only, and 10% percent requested KR *randomly*, and the remaining 20% of participants requested KR through a strategy not listed on the questionnaire (e.g., “I wanted feedback all the time” and “always asked for feedback”). When asked to report when they did *not* ask for KR, 30% of the SELF-OLD participants reported after *perceived bad trials* only, 10% of participants reported after *good and bad trials* equally, 10% reported *randomly*, and 50% of participants reported a strategy that was not listed on the questionnaire. Such individualized strategies were identified as “always asked for feedback”.

In the YOKED-YOUNG condition, 50% of participants reported they *received KR after the right trials*. Of the 50% of participants that reported they *did not receive KR after the right trials*, 100% of them reported they would have preferred to receive KR after *perceived good trials* only. In the YOKED-OLD condition, 70% of participants reported they *received KR after the right trials*. Of the 30% of participants that reported they *did not receive KR after the right trials*, 100% of them reported they would have preferred to receive KR after *perceived good and bad trials* equally. In summary, the results from the questionnaire data revealed that the self-reported KR scheduling strategies were differentially impacted as a function of age and amount of practice.

4.6. Self-reported use of intrinsic feedback sources

One purpose of the present experiment was to determine whether a self-controlled KR schedule would facilitate a reference of correctness of a spatial motor task whereby participants would be able to rely on their proprioceptive feedback rather than an external source. To investigate this, the questionnaire used by Anderson et al. (2005) was modified to assess the sensory information utilized by the participants during the acquisition period. The results of the questionnaire are displayed in Table 3.

Table 3

Self-reported use of intrinsic feedback sources by self and yoked participants during acquisition

KR condition	Younger adults	Older adults
Self-control condition	Number of responses	
1. <i>During practice, did you use/interpret any other sources of information in addition to KR or when KR was not available?</i>		
a) Yes	10	10
b) No	0	0
2. <i>If the answer to the above question was YES, please indicate all the sources you used/interpreted during practice.</i>		
a) hand position	3	6
b) wrist position	2	3
c) arm position	1	7
d) elbow position	0	0
e) shoulder position	0	6
f) produced force	10	10
g) other	0	1
Yoked condition	Number of responses	
1. <i>During practice, did you use/interpret any other sources of information in addition to KR or when KR was not available?</i>		
a) Yes	10	7
b) No	0	3
2. <i>If the answer to the above question was YES, please indicate all the sources you used/interpreted during practice.</i>		
a) hand position	9	7
b) wrist position	1	7
c) arm position	10	5
d) elbow position	0	0
e) shoulder position	0	4
f) produced force	8	7
g) other	0	0

Note. This KR preference questionnaire was modified for this experiment based on the questionnaire used by Anderson et al. (2005).

The participants in the SELF-YOUNG, SELF-OLD, and YOKED-YOUNG conditions all reported they interpreted additional information to KR during the acquisition period, whereas seven of the 10 participants in the YOKED-OLD condition reported the use of additional information. One of the most interesting findings from the questionnaire data was the reported interpretation of a greater variety of additional information during acquisition by the SELF-OLD (e.g., hand position, arm position, shoulder position, and produced force), the YOKED-YOUNG (e.g., hand position, arm position, and produced force), and the YOKED-OLD (e.g., hand position, wrist position, and produced force) conditions. Moreover, participants in the SELF-YOUNG condition were more likely to utilize one source of additional information (e.g., produced force) whereas those in the SELF-OLD, YOKED-YOUNG, and YOKED-OLD were more likely to rely on four sources, three sources, and five sources of additional information, respectively. Further, participants were also asked to self-report whether their reported use of the various sources of information changed throughout practice. In the SELF-YOUNG condition, two participants reported a change during practice. For example, one participant reported “I would use different combinations of *hand position*, *wrist position*, and *produced force* but found that *produced force* was the easiest to interpret” while the other participant described a similar experience, “as I became more familiar and better at the task, I began to pay more attention to how each throw felt over *hand* and *wrist positions* and asking for feedback.” In the YOKED-YOUNG condition, only one participant reported a change during practice. This change was described as “I used different combinations all the time to try and increase my consistency.” No participants in either the SELF-OLD or the YOKED-OLD conditions reported a change in their use of the different sources of intrinsic feedback.

CHAPTER 5: DISCUSSION

The primary purpose of this thesis was two-fold. First, to examine the utility of a self-controlled KR schedule during the acquisition of a spatial motor task in younger and older adults and second, to determine whether a self-controlled KR schedule facilitates an increased ability to estimate one's performance in retention and transfer. Of secondary interest was to determine if participants' preferences for requesting KR would change as a function of number of practice trials completed and age. To answer these research questions, the following predictions were made: first, irrespective of age, the SELF conditions would perform more accurately (e.g., less |CE|) in retention and transfer than the YOKED conditions (Chiviawosky & Wulf, 2002; 2005; Patterson & Carter, 2010; Patterson et al., in press). Second, participants in the SELF conditions would be more accurate in estimating their performance in retention and transfer compared to the YOKED conditions. This prediction is based on previous research revealing a decreased reliance on the practice variable being controlled during acquisition (Janelle et al., 1995; Janelle et al., 1997; Wulf et al., 2005; Wulf & Toole, 1999). Third, participants in the SELF-OLD condition would bias towards less effortful KR schedules (e.g., high frequency of KR requests) compared to the SELF-YOUNG condition based on findings from the cognitive learning literature where older adults consistently self-select the less effortful learning strategy (Hertzog et al., 2007; Rogers et al., 2000; Touron et al., 2004; Touron & Hertzog, 2004). In fact, when a learner experiences high frequency KR schedules during acquisition, it has been suggested to undermine motor learning (Ishikura, 2008; Lee et al., 1994; Salmoni et al., 1984; Steinhauer & Grayhack, 2008; Winstein & Schmidt, 1990; Wulf & Shea, 2004). Lastly, it was predicted that irrespective of KR condition, younger adults would perform more accurately (e.g., less |CE|) and more consistently (e.g., less VE) than the older adults in all experimental phases (Swanson & Lee, 1992; Wishart & Lee, 1997; Wishart et al., 2002). The results of the experiment suggest that as a function of age, a self-

controlled KR schedule facilitated superior retention performance and more accurate performance estimations in retention; thus, the first and second predictions were not supported. Although the SELF-YOUNG condition reported a different preference for KR during acquisition compared to the SELF-OLD condition, the relative frequency that KR was requested by the SELF-YOUNG condition ($M = 64.6\%$, $SD = 27\%$) was not statistically different than the SELF-OLD condition ($M = 74.1\%$, $SD = 35\%$). As a result, the third prediction was not supported. The final prediction of this thesis was supported in acquisition and retention because irrespective of KR condition, the younger adults performed with less $|CE|$ and less VE compared to the older adults; however, this was not supported during transfer. A discussion of these findings follows.

5.1. Learning benefits of a self-controlled KR schedule as function of age

The extant motor learning research has unequivocally revealed that providing younger adults with the opportunity to actively decide *when to receive* and *not to receive* KR after each acquisition trial is advantageous for motor learning (Chen et al., 2002; Chiviacowsky & Wulf, 2002; 2005; Patterson & Carter, 2010; Patterson et al., in press). The main interest of this thesis was to determine if the previously found learning benefits of a self-controlled KR schedule would extend to older adults during the acquisition of a novel motor task. Based on the existing literature, it was predicted that independent of age, participants in the SELF conditions would demonstrate superior retention (Chen et al., 2002; Patterson & Carter, 2010; Patterson et al., in press) and transfer (Chiviacowsky & Wulf, 2002; 2005; Patterson et al., in press) performance compared to their YOKED counterparts. Consistent with previous research, the SELF-YOUNG condition was significantly more accurate in achieving the spatial goal during retention compared to the YOKED-YOUNG condition. It was important to replicate the learning benefits of a self-controlled KR schedule from previous studies based on the fact the present experiment used a motor task with a spatial goal rather than the more commonly used temporal goal (Chen et al.,

2002; Chiviawsky & Wulf, 2002; 2005; Patterson & Carter, 2010; Patterson et al., in press).

The use of a spatial goal rather than a temporal goal was not expected to require processing differences because it is viewed that spatial and temporal information are generally processed together (Mauk & Buonomano, 2004). However, unlike Chiviawsky & Wulf (2002; 2005), no significant differences were found between the SELF-YOUNG and the YOKED-YOUNG conditions during transfer. The equivalent performance of the SELF-YOUNG and the YOKED-YOUNG conditions during transfer suggests that it was the *frequency* that KR was received during acquisition that facilitated performance when asked to generalize their learning to a novel variation of the task (e.g., 165 cm). In contrast to the first prediction, the SELF-OLD and the YOKED-OLD conditions demonstrated equivalent retention and transfer performances. Reasons for this equated performance are discussed next.

The first explanation to consider why the learning advantages of self-control did not extend to older adults in the current study is the heightened cognitive demands in a self-control condition. It has been demonstrated that an increase in cognitive demands during practice leads to greater learning of that task as measured by retention and transfer tests (see Lee et al., 1994 for a review). A fundamental component of practicing in a self-controlled context is that it inherently requires a greater investment of cognitive resources of the learner (Kanfer & Ackerman, 1989; Patterson et al., 2009). A self-controlled KR schedule is considered to be inherently cognitively effortful because the learner must decide after every trial if KR is required. This decision is based on an attempt to resolve any discrepancies between the interpretation of their intrinsic feedback and their actual performance. In comparison, the provision of KR in a yoked condition or an experimenter-defined KR schedule is predetermined rather than being actively individualized from one trial to the next. In fact, previous research has attributed the superior learning in the self-control conditions to these increased demands on cognition to actively control a practice

variable (Hartman, 2007; Janelle et al., 1997; Wu & Magill, 2004). Furthermore, it has been demonstrated that advancing age is accompanied by a reduction in cognitive processing abilities (e.g., attention, working memory) (Bäckman et al., 2000; Bäckman et al., 2010; Drag & Bieliauskas, 2010; Fjell & Walhoud, 2010; Luo & Craik, 2008; Salthouse, 1996). Therefore, the increased demands on cognitive processing required to individualize a learning context may have negated the previously found learning benefits by exceeding the already compromised cognitive processing abilities of the older adults. When older adults are provided with the opportunity to control an aspect of their practice context, they adopt less effective strategies for learning motor (Patterson et al., 2009) and cognitive tasks (Hertzog et al., 2007; Rogers et al., 2000; Touron et al., 2004; Touron & Hertzog, 2004). When older adults were permitted to self-select a learning strategy for a cognitive or verbal task, they consistently favoured the least effortful strategy (e.g., recognition or scanning) rather than the more effective learning strategy where a high degree of cognitive effort was required (e.g., retrieval). A similar finding was seen in Patterson et al. (2009), where older adults preferred high frequency KR schedules (92.5% of trials) with 70% of participants requesting KR after every trial during acquisition. It has been demonstrated that a high frequency KR schedule during acquisition can be detrimental to learning (e.g., guidance hypothesis) because it reduces the cognitive load on the learner that is experienced when KR is not provided (Lee et al., 1994; see Salmoni et al., 1984 and Wulf & Shea, 2004 for reviews). Yet, when given control over an aspect of their practice, older adults prefer a context placing low demands on their cognitive processes (Hertzog et al., 2007; Patterson et al., 2009; Rogers et al., 2000; Touron et al., 2004; Touron & Hertzog, 2004). Therefore, older adults may prefer a high frequency KR schedule to decrease the demands on their cognitive processes afforded by a self-control practice context. Consequently, it appears the frequency that KR is provided and not the decision to receive or not to receive KR may be the main factor facilitating performance and

subsequent learning in older adults based on the similar motor performance of the SELF-OLD and YOKED-OLD conditions.

The cognitive effort argument eventually falls short in explaining the inability to replicate the benefits of self-control in older adults. If an overburdened cognitive system was the sole mechanism compromising learning in a self-controlled context, then it would be expected that the YOKED-OLD condition would demonstrate superior learning to the SELF-OLD condition. Specifically, practicing in a yoked condition does not encompass the same inherent increased demands on cognitive processes since yoked participants are not required to make decisions based on a practice variable being controlled. Consistent with Patterson et al. (2009), it is believed that the equivalent performance between the SELF-OLD and YOKED-OLD participants resulted from the frequency KR was requested during acquisition. Wishart et al. (2002) found older adults required concurrent feedback on every trial to facilitate learning of a novel bimanual coordination pattern. Similarly, older adults learned an isometric force production task when KR or kinetic feedback was presented at the end of every acquisition trial (van Dijk et al., 2007). Therefore, when increased demands are placed on sensorimotor integration as in the current experiment, older adults appear to benefit from KR that is provided on a high proportion of trials for continuous (Wishart et al., 2002) and discrete (van Dijk et al., 2007) motor tasks.

Overall, the results of the present experiment suggest that the learning benefits of a self-controlled KR schedule in younger adults did not extend to older adults compared to their respective yoked condition, thus failing to support the first prediction. However, it is important to note that this inability to replicate the learning benefits of a self-controlled KR schedule in older adults was not due to a lack of motor learning but instead was the result of the SELF-OLD condition failing to learn the motor task to a significantly greater degree compared to the YOKED-OLD condition. This was determined by comparing the |CE| for blocks 1, 10 and

retention (collapsed to include both immediate and delayed retention) (see Figure 5). The statistical analysis revealed that block 1 was performed with greater $|CE|$ than block 10 and retention for the SELF-YOUNG, the SELF-OLD, and the YOKED-OLD condition whereas block 1 was performed with more $|CE|$ than only block 10 for the YOKED-YOUNG condition. Therefore, it can be concluded that the SELF-YOUNG, SELF-OLD, and the YOKED-OLD condition learned the motor task relative to their baseline performance in block 1.

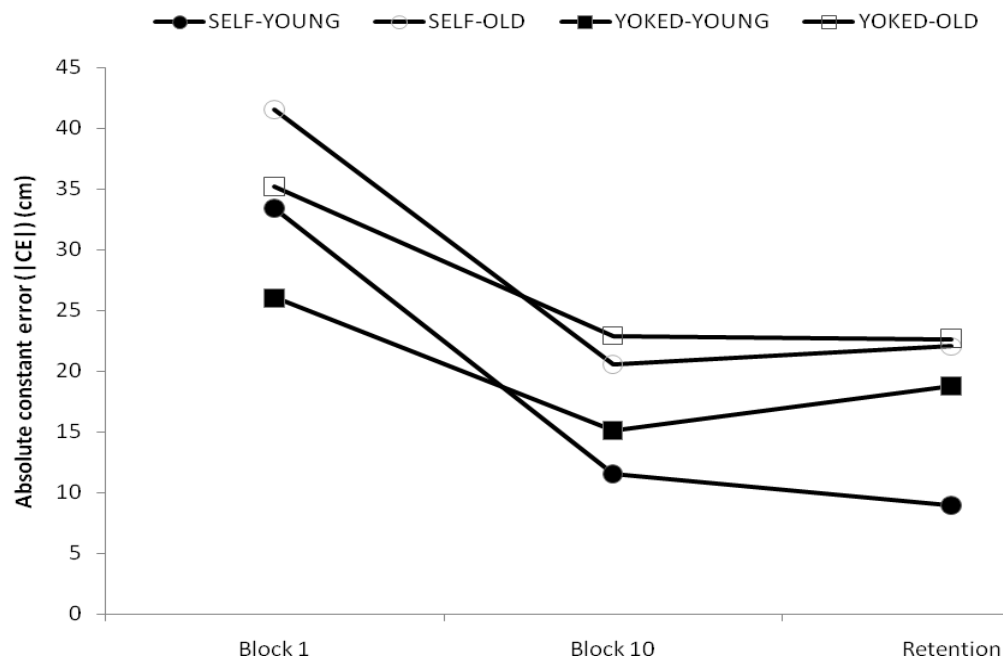


Figure 5. Relative learning (indexed by $|CE|$) for all experimental conditions by comparing $|CE|$ for retention (collapsed across retention tests) to $|CE|$ for block 1 and 10 of acquisition.

5.2. Performance estimation abilities as a function of KR condition

One of the primary purposes of this thesis was to propose a possible mechanism underlying the learning benefits of a self-controlled KR schedule. Thus, we were interested in

determining if a self-controlled KR schedule would facilitate the development of an accurate reference of correctness of the to-be-learned motor task, expected to be evidenced by subjective performance estimations. Previous self-control research has revealed participants systematically decrease their reliance on the practice variable being controlled during acquisition (Janelle et al., 1995; Janelle et al., 1997; Wulf et al., 2005; Wulf & Toole, 1999). For example, Janelle et al. (1997) found that participants decreased their receipt of KR from 9.1% of trials in block one to 2.9% by block 20 while Wulf & Toole (1999) found that during practice on day one, participants requested the use of an assistive device (e.g., ski poles) for 92% of the time on trial one and gradually reduced it to 54% by the last trial. A similar decrease was found on day two of practice with the ski poles being requested for 85% of the time on trial one and only 25% by the last trial. However, these studies did not examine if this decreased reliance on the practice variable was superseded by an increased reliance on intrinsic sources of information. To address this void in knowledge, we asked participants to make performance estimations after each no-KR trial during retention and transfer (e.g., how far do you think the slide went?). We assessed performance estimations of participants only in retention and transfer for two reasons. First, we were not interested in explicitly training estimation abilities through manipulations made during the acquisition period (e.g., Guadagnoli & Kohl, 2001; Liggins, Li, Stephens & Lai, 2007; Sherwood, 2008; Swinnen et al., 1990). Instead, we were interested in determining if the ability to make accurate performance estimation was an inherent product of a self-controlled KR schedule. Second, if performance estimations were made during practice, this would have confounded the results of the experiment since it would be problematic to determine which practice manipulation, self-control or estimating one's performance was responsible for facilitating motor learning. Based on previous research identifying a systematic decreased reliance on the practice variable being controlled during acquisition, our second prediction stated that irrespective of age,

participants in the SELF conditions would make more accurate performance estimations than their YOKED counterparts, to be evidenced by less AD.

The post-hoc analysis of the interaction between condition and age revealed that the SELF-YOUNG condition was significantly more accurate in their performance estimations during retention compared to the YOKED-YOUNG condition, yet the SELF-OLD condition was not significantly different from the YOKED-OLD condition. As a result, the second prediction was not supported in retention. Our second prediction was also not supported in transfer as the main effect for condition failed to reach statistical significance. Contrary to our second prediction, we found a significant main effect for age for performance estimations in transfer where the younger adults were more accurate in estimating their performance compared to the older adults. These findings suggest that younger adults that practice in a self-controlled KR schedule become more perceptually aware of their intrinsic feedback sources and can successfully interpret this information to benefit motor learning. Therefore, extending our theoretical understanding of the learning advantages associated with a self-controlled KR schedule in younger adults. To our knowledge, this was the first experiment to suggest a potential mechanism responsible for the learning benefits of a self-controlled KR schedule in younger adults. To account for the SELF-OLD condition failing to make significantly more accurate performance estimations in retention compared to their YOKED counterparts, two alternative hypotheses are proposed. First, previous research suggests older adults are more sensitive to their practice context when increased demands are placed on their sensorimotor processing, specifically proprioceptive information (Adamo et al., 2007; Meeuwsen et al., 1993). In Meeuwsen et al. (1993), participants actively held a reference position with one foot and were required to match it with their other foot. Meeuwsen et al. (1993) discovered that older adults had greater difficulty integrating afferent information from the talocrural joint which resulted in less overall response

accuracy and increased response variability for the foot position matching task. Adamo and colleagues (2007) extended the lower limb findings of Meeuwsen et al. (1993) to upper limb proprioception at the elbow. The findings of Adamo et al. (2007) were similar to Meeuwsen et al. (1993) with older adults demonstrating a decreased ability to use proprioceptive information for the elbow matching task which resulted in an increase in matching errors compared to the younger adults. In the current study, both visual and auditory feedback was controlled for to ensure that proprioception was the sole source of intrinsic feedback always available to the learner. Similar to Adamo et al. (2007), our spatial motor task required the integration of proprioceptive information from the upper limb. Therefore, these decreases in proprioceptive acuity in older adults may have been a potential factor contributing to their difficulty in calibrating a successful motor response from proprioceptive information.

A second explanation for the lack of dissociated differences in performance estimations between the SELF-OLD and the YOKED-OLD conditions may be related to the frequency that KR was requested by the SELF-OLD participants. The third prediction of this thesis stated that the SELF-OLD condition would create less effortful KR schedules compared to the SELF-YOUNG condition. The mean frequencies of KR for the SELF-YOUNG ($M = 64.6\%$, $SD = 27\%$) and the SELF-OLD ($M = 74.1\%$, $SD = 35\%$) conditions were not significantly different, failing to support this prediction. However, it is important to note that 70% of the older adult participants created a high frequency KR schedule ($\geq 87\%$) during acquisition. Interestingly, previous studies have shown that a high frequency KR schedule can facilitate motor skill acquisition in older adults (e.g., van Dijk et al., 2007; Wishart et al., 2002) and in individuals who have experienced changes in their sensory system such as Parkinson's Disease (Guadagnoli, Leis, Van Gemmert & Stelmach, 2002). However, in the present experiment it is believed that these high frequency KR schedules hindered the ability of the older adults to utilize intrinsic feedback since the majority of

older adults either never experienced a no-KR trial or only a small proportion of no-KR trials during acquisition. A critical characteristic of an effective KR schedule is that it should require participants to learn to interpret and utilize motor response intrinsic feedback, thereby facilitating the development of a reference of correctness (Lee et al., 1994; Salmoni et al., 1984). When a high frequency KR schedule is experienced during practice, the participant is not forced to learn to interpret and use intrinsic feedback sources such as proprioception because a dependence on the provision of KR typically occurs (Ishikura, 2008; Salmoni et al., 1984; Steinhauer & Grayhack, 2000; Winstein & Schmidt, 1990). Interestingly, the ability to successfully use intrinsic feedback sources to detect and correct errors is essential to motor learning since it is always available to the learner (Bruechert et al., 2003; Lee et al., 1994; Wulf & Shea, 2004). Therefore, it is expected that experiencing more no-KR trials during acquisition would require the learner to become more aware of intrinsic feedback and this increased reliance would directly influence the ability to make accurate performance estimations. The individual KR schedules created by the SELF-YOUNG participants consisted of a greater proportion of no-KR trials, suggesting a strengthened reference of correctness, evidenced by performance estimations that were significantly more accurate than their YOKED counterparts. In contrast, although the individualized KR schedule of the SELF-OLD participants facilitated learning, it was detrimental to the development of their reference of correctness. As a result, the SELF-OLD participants failed to make performance estimations that were significantly more accurate than those of the YOKED-OLD participants.

In summary, it was predicted that the SELF-OLD condition would make significantly more KR requests during acquisition compared to the SELF-YOUNG condition for learning the spatial motor task. However, both conditions learned the task and requested KR at similar frequencies, failing to support our third prediction.

5.3. Self-reported use of intrinsic feedback sources during acquisition

Similar to Anderson et al. (2005), we were interested in determining the different sources of intrinsic information participants may have relied on during acquisition. Upon completion of all experimental phases, all participants completed a questionnaire querying the use of intrinsic sources of feedback during the acquisition phase on day one (see Table 3). All 10 participants in the SELF-YOUNG, SELF-OLD, and YOKED-YOUNG condition and seven participants in the YOKED-OLD condition reported the use of intrinsic feedback. The SELF-YOUNG and the YOKED-YOUNG participants reported interpreting information from the same four sources: hand position, wrist position, arm position, and produced force. Interestingly, these same four sources were reported by the SELF-OLD and the YOKED-OLD conditions; however, both conditions identified the use of additional sources to these four. The SELF-OLD condition reported the use of shoulder position and a source not listed on the questionnaire (e.g., knee position) while the YOKED-OLD condition also reported the use of shoulder position. The number of intrinsic feedback sources that were reported varied as a function of KR condition and age. The SELF-YOUNG condition (6 out of 10) primarily relied on one source of information whereas the YOKED-YOUNG condition (8 out of 10) relied on three sources of intrinsic feedback. The SELF-OLD condition (5 out of 10) mainly relied on four sources of intrinsic information while the YOKED-OLD condition (4 out of 7) relied on five sources. The SELF-YOUNG condition demonstrated a strong preference for produced force as their main source of intrinsic feedback. The other experimental conditions also reported using produced force; however, in addition to produced force, the SELF-OLD, YOKED-YOUNG, and YOKED-OLD participants chose to augment this information through the use of other sources of intrinsic feedback. Overall, these results suggest that the SELF-YOUNG condition adopted a more

specific strategy (one source) in their interpretation of intrinsic feedback compared to the more general strategy (three or more sources) by the other experimental conditions.

A possible reason to explain why the YOKED-YOUNG participants may have used a more general strategy (produced force + additional sources) compared to the SELF-YOUNG condition is that of a compensatory mechanism during no-KR trials. The SELF-YOUNG condition had the opportunity to control when a KR or a no-KR trial would occur. In comparison, the YOKED-YOUNG condition received KR based on the individualized schedule of a SELF participant without the choice of when KR would be provided. As a result, the YOKED-YOUNG participants may have supplemented their interpretation of produced force with additional intrinsic feedback for trials they did not receive KR but would have preferred to.

The older adults, irrespective of KR condition also seemed to adopt a more general strategy, similar to the YOKED-YOUNG condition (produced force + additional sources). The older adults seemingly selected this general strategy as a compensatory mechanism for declines in cognitive processing similar to what is found in the cortical activation patterns (e.g., posterior-anterior shift) of older adults during highly demanding cognitive tasks involving working memory, visuospatial processing, and attention (Davis, Dennis, Daselaar, Fleck & Cabeza, 2008). The posterior-anterior shift involves an increased activation in anterior regions (e.g., pre-frontal and frontal cortex) of the brain to compensate for processing deficits in more posterior regions, such as those areas associated with sensory processing (Drag & Bieliauskas, 2010; Grady, Maisog, Horwitz, Ungerleider, Mentis, Salerno, Pietrini, Wagner & Haxby, 1994). Therefore, to have a similar amount of cognitive resources available as a younger adult, the older adult must recruit and rely on a greater number of brain regions. Due to reductions in sensorimotor processing (Adamo et al., 2007; Meeuwsen et al., 1993; Seidler, 2006), the older adults may need to rely on intrinsic information from a greater number of sources to create their reference of

correctness for a spatial motor task. However, based on information processing, the older adults may have overloaded their cognitive system by choosing to interpret multiple sources of intrinsic information.

In summary, it appears that KR condition and age influenced which sources of intrinsic feedback and the number of sources that were interpreted. The SELF-YOUNG condition demonstrated a preference for a more specific strategy by primarily interpreting produced force, whereas the SELF-OLD, YOKED-YOUNG, and YOKED-OLD conditions opted for a more general strategy by interpreting multiple sources in addition to produced force.

5.4. Self-reported KR preferences during acquisition

Chiviacowsky & Wulf (2002) was the first self-control study to examine the preferences for KR during practice through the use of a questionnaire at the conclusion of practice. It was discovered that when participants controlled their receipt of KR, a preference for KR after a *perceived good trial* emerged. Since Chiviacowsky & Wulf (2002), this preference has been replicated in other experiments using self-controlled KR schedules and administering a similar questionnaire (Patterson & Carter, 2010; Patterson et al., in press). In the present study, the preferences for KR of the SELF conditions were differentially impacted by the stage of practice (e.g., first half [blocks 1-5] and second half [blocks 6-10]) and age (see Table 2). During the first half of acquisition, the SELF-YOUNG and the SELF-OLD conditions both reported a preference for KR after *perceived good and bad trials equally*. A preference for KR after *good and bad trials equally* early in practice intuitively makes sense as this strategy would involve feedback after a greater proportion of trials. This increased amount of KR may be used by the learner to calibrate a performance hypothesis by *pairing* KR with their interpretation of what a *good trial* and a *bad trial* feels like through intrinsic feedback. However, during the second half of practice the SELF-

YOUNG condition switched their preference for KR to after *perceived good trials only* (80% compared to 40% in the first half), consistent with previous research (Chiviacowsky & Wulf, 2002; Patterson & Carter, 2010; Patterson et al., in press). Interestingly, the SELF-OLD condition maintained the same preference for KR after *perceived good and bad trials equally* (50% and 50%). Therefore, during the second half of practice (blocks 6 to 10) the SELF-YOUNG condition utilized a more specific KR strategy (perceived good trials) which resulted in superior retention performance compared to a more generalized KR strategy (perceived good and bad trials equally) utilized by the SELF-OLD condition. In fact, recent research has revealed that KR after *good trials* compared to *poor trials* facilitated greater retention performance of a bean bag tossing task in younger adults (Chiviacowsky & Wulf, 2007) and older adults (Chiviacowsky & Wulf, 2009). It was concluded that when KR is provided after *good trials*, it may encourage the participant to repeat that movement through a reinforcement mechanism (Chiviacowsky & Wulf, 2007; 2009). Moreover, feedback provided after *good trials* is associated with a decreased demand on cognitive resources because it is believed that repeating a successful movement is less cognitively demanding than making corrections based on an unsuccessful response (Koehn, Dickinson & Goodman, 2008).

In addition, neuroimaging studies have identified increased levels of activity in the dopaminergic cortical pathways of the brain when feedback is provided after *good trials* (Declerck, Boone & de Brabander, 2006; Kühn, Brücke, Hübl, Schneider, Kupsch, Eusebio, Ashkan, Holland, Aziz, Vandenberghe, Nuttin & Brown, 2008). According to the dopamine hypothesis of cognitive aging, there is a dysregulation of dopamine that occurs in multiple areas of the aging brain, especially in the frontal cortex (Nieoullon, 2002; Suhara, Fukuda, Inoue, Itoh, Yamasaki & Tateno, 1991). Furthermore, numerous cognitive functions are highly linked to dopamine (Nieoullon, 2002) and these age-related changes in the dopaminergic pathways of the

brain may be responsible for the decreased cognitive abilities and subsequent learning in older adults since these dopaminergic pathways are considered essential for learning (Declerck et al., 2006; Drag & Bieliauskas, 2010; Kühn et al., 2008). When participants in the YOKED-YOUNG and YOKED-OLD conditions were asked if they *received KR after the right trials*, five younger adults and three older adults reported they *did not receive KR after the right trials* during acquisition. The five YOKED-YOUNG participants would have requested KR after *perceived good trials* whereas the three YOKED-OLD participants would have preferred KR after *perceived good and bad trials equally*. Thus, the preferences reported by the YOKED participant mirror the KR preferences for the second half of acquisition of their age-matched SELF counterparts.

5.5. Movement accuracy and stability as a function of age

The final prediction of this thesis was that irrespective of condition, the younger adults would have less |CE| and less VE than the older adults in all experimental phases. This was supported for both variables in acquisition and retention and only for |CE| in transfer. These differences are predicted to be associated with previously identified age-related changes in the ability to accurately process cognitive (Bäckman et al., 2000; Bäckman et al., 2010; Drag & Bieliauskas, 2010; Fjell & Walhoud, 2010; Luo & Craik, 2008; Salthouse, 1996) and sensorimotor (Adamo et al., 2007; Meeuwsen et al., 1993; Seidler, 2006; Seidler & Stelmach, 1995) information. The differences in movement accuracy and stability in the present experiment are consistent with previously found differences in motor performance between younger adults and older adults that have identified that younger adults perform more accurately and more consistently than older adults (Carnahan et al., 1996; Enoka et al., 2003; Sosnoff & Newell, 2006; Swanson & Lee, 1992; Wiegand & Ramella, 1983; Wishart & Lee, 1997; Wishart et al., 2002).

5.6. Summary of findings

The results of the present experiment suggest that a self-controlled KR schedule did not facilitate superior retention or transfer performance in older adults compared to their respective yoked condition. This finding is not commensurate with the younger adult literature examining the utility of a self-controlled KR schedule (Chen et al., 2002; Chiviacowsky & Wulf, 2002; 2005; Patterson et al., 2010; Patterson et al., in press), and fails to support our first prediction. Furthermore, the findings suggest that an increased ability to utilize intrinsic feedback to make performance estimations is an inherent feature of a self-controlled KR schedule and may be a possible mechanism responsible for the previously found learning benefits of self-controlled KR schedules. However, it appears this increased ability to interpret intrinsic feedback to make performance estimations is a function of age. As a result, our second prediction was supported in younger adults but not in older adults. Lastly, the results from this thesis suggest the preferences for requesting KR during acquisition differ as a function of practice (first half compared to second half) and age (younger adults compared to older adults).

CHAPTER 6: CONCLUSIONS

6.1. Summary of contributions to the existing literature

The results of this thesis add to our theoretical understanding of the learning benefits of a self-controlled KR schedule in younger adults in two important ways. First, practicing in a self-controlled context is accompanied by an inherent increased ability to use intrinsic information to make accurate performance estimations in no-KR retention tests. Second, younger adults that controlled their receipt of KR during acquisition utilize unique KR scheduling strategies based on the stage of acquisition. During the early portion of practice, there is a strong preference for KR after *perceived good and bad trials equally*; possibly as a way to successfully differentiate between what a *good trial* and a *bad trial* feels like in order to calibrate their reference of correctness. Whereas during the second half of practice, there is a self-reported switch from this more general KR preference to the more effective and more specific KR strategy of requesting after *perceived good trials only* (Chiviacowsky & Wulf, 2002; 2007; 2009; Patterson & Carter, 2010; Patterson et al., in press). Finally, the results of this study strengthens the growing body of evidence demonstrating the effectiveness of a self-controlled KR schedule for motor skill acquisition in younger adults (Chiviacowsky & Wulf, 2002; 2005; Patterson & Carter, 2010; Patterson et al., in press). However, consistent with Patterson et al. (2009), the effectiveness of a self-controlled KR schedule in older adults is not well understood and consequently remains a fruitful area of further investigation.

6.2. Suggestions for future studies

Future studies examining age-related differences in motor learning from self-controlled practice contexts should change their focus of KR to other practice variables that have been successfully controlled in previous studies, such as repetition schedules, frequency of observing a

modeled demonstration, frequency of using an assistive device, and the frequency of receiving KP. Based on the findings of this thesis and those affording older adults control in their practice schedule (Hertzog et al., 2007; Patterson et al., 2009; Rogers et al., 2000; Touron et al., 2004; Touron & Hertzog, 2004), it appears that older adults are unable to create an effective practice schedules to facilitate learning. Therefore, examining whether changing the proportion of control trials afforded to the older adult learner as in Patterson et al. (in press), would facilitate the generation of a more effective feedback schedule and increase subsequent learning. When younger adults practiced in an experimenter-defined KR schedule prior to a self-controlled KR schedule learning was not enhanced compared to a 100% self-controlled schedule (Patterson et al., in press). This is not surprising as past research has convincingly revealed that younger adults are able to control a portion of their practice context to facilitate learning. In contrast, the extant literature strongly suggests that older adults are not able to benefit from self-control over all acquisition trials. Perhaps having older adults practice in a pre-defined KR schedule, previously shown to facilitate motor learning (e.g., faded-KR schedule), prior to the self-control trials is required for older adults to create more effective KR schedules during practice. Lastly, future investigations of self-controlled practice in motor learning should continue to explicitly attempt to capture the mechanisms responsible for the learning benefits of self-control as this will extend our knowledge in the development of more effective rehabilitation, vocational, and recreational programs.

6.3. Limitations

The current thesis, like all experiments is not free from limitations. One factor to consider in future investigations is the unit in which KR was presented to the participants. Knowledge of results in the current study was provided to participants using the metric system. This is the unit of measurement that is currently used in the Canadian education system; however, at the end of

the study many older adult participants mentioned they were unfamiliar with the metric system because they grew up with the imperial system as the standard unit of measurement. Therefore, future studies examining motor skill acquisition with a spatial goal in older adults should determine the participant's familiarity with the unit of measurement being used prior to the experimental testing phases. Another possible limitation in this study could have been the number of acquisition trials. Although learning of a motor task has occurred using 60 trials in previous experiments (Chiviawowsky et al., 2008 - children; Chiviawowsky & Wulf, 2007 – younger adults; Chiviawowsky & Wulf, 2009 – older adults), perhaps older adults require a greater number of acquisition trials to not only successfully control a practice variable for the duration of practice but to also develop a reference of correctness for a motor task.

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Appendix A

Mini-Mental State Examination (Folstein, Folstein & McHugh, 1975)

Mini-Mental State Examination (MMSE)

Patient's Name: _____ Date: _____

Instructions: Ask the questions in the order listed. Score one point for each correct response within each question or activity.

Maximum Score	Patient's Score	Questions
5		"What is the year? Season? Date? Day of the week? Month?"
5		"Where are we now: State? County? Town/city? Hospital? Floor?"
3		The examiner names three unrelated objects clearly and slowly, then asks the patient to name all three of them. The patient's response is used for scoring. The examiner repeats them until patient learns all of them, if possible. Number of trials: _____
5		"I would like you to count backward from 100 by sevens." (93, 86, 79, 72, 65, ...) Stop after five answers. Alternative: "Spell WORLD backwards." (D-L-R-O-W)
3		"Earlier I told you the names of three things. Can you tell me what those were?"
2		Show the patient two simple objects, such as a wristwatch and a pencil, and ask the patient to name them.
1		"Repeat the phrase: 'No ifs, ands, or buts.'"
3		"Take the paper in your right hand, fold it in half, and put it on the floor." (The examiner gives the patient a piece of blank paper.)
1		"Please read this and do what it says." (Written instruction is "Close your eyes.")
1		"Make up and write a sentence about anything." (This sentence must contain a noun and a verb.)
1		"Please copy this picture." (The examiner gives the patient a blank piece of paper and asks him/her to draw the symbol below. All 10 angles must be present and two must intersect.) 
30		TOTAL

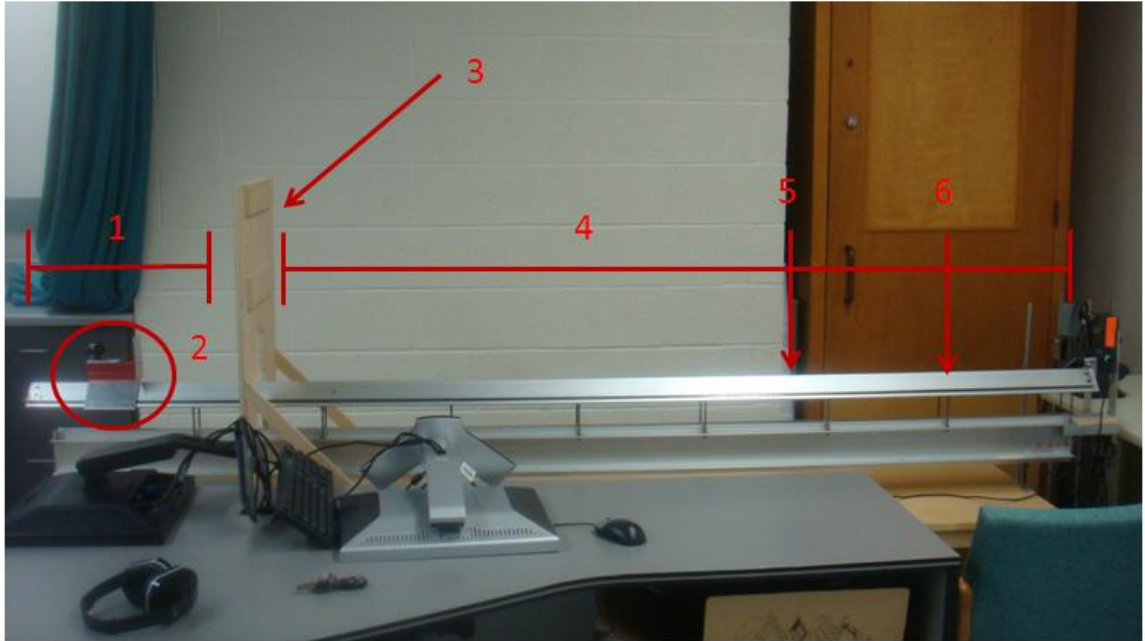
Appendix B

The Barthel Index

Participant: _____ Rater: _____ Date: _____	
Activity	Score
FEEDING 0 = unable 5 = needs help cutting, spreading butter, etc., or requires modified diet 10 = independent	0 5 10
BATHING 0 = dependent 5 = independent (or in shower)	0 5
GROOMING 0 = needs to help with personal care 5 = independent face/hair/teeth/shaving (implements provided)	0 5
DRESSING 0 = dependent 5 = needs help but can do about half unaided 10 = independent (including buttons, zips, laces, etc.)	0 5 10
BOWELS 0 = incontinent (or needs to be given enemas) 5 = occasional accident 10 = continent	0 5 10
BLADDER 0 = incontinent, or catheterized and unable to manage alone 5 = occasional accident 10 = continent	0 5 10
TOILET USE 0 = dependent 5 = needs some help, but can do something alone 10 = independent (on and off, dressing, wiping)	0 5 10
TRANSFERS (BED TO CHAIR AND BACK) 0 = unable, no sitting balance 5 = major help (one or two people, physical), can sit 10 = minor help (verbal or physical) 15 = independent	0 5 10 15
MOBILITY (ON LEVEL SURFACES) 0 = immobile or < 50 yards 5 = wheelchair independent, including corners, > 50 yards 10 = walks with help of one person (verbal or physical) > 50 yards 15 = independent (but may use any aid; for example, stick) > 50 yards	0 5 10 15
STAIRS 0 = unable 5 = needs help (verbal, physical, carrying aid) 10 = independent	0 5 10
TOTAL (0 – 100)	_____

Appendix C

Image of task apparatus



Note. 1 – Warm-up area; 2 – Slide; 3 – Wooden barrier; 4 – Scoring zone; 5 –Approximate acquisition and retention goal; 6 – Approximate transfer goal

Appendix D

Image of Vernier Motion Detector



Appendix E

Image of Vernier LabPro



Appendix F

Relative Friction Information

Testing Day	Distance
1	107.696
2	107.447
3	108.863
4	106.086
5	107.974
6	106.891
7	108.747
8	106.947
9	108.113
10	106.142
11	106.641
12	106.003
13	108.724
14	107.446
15	107.203
16	106.782
17	107.446
18	106.891
19	106.725
20	108.057
21	108.002
22	107.474
23	106.447
Mean (SD)	107.325 (0.826)

Note: The relative friction was determined on each testing day prior to testing using a constructed pulley-system. The pulley-system consisted of a cable wire (215cm) that would get connected to the slide at one end using a fishing clip and a weight (505g) was attached at the opposite end.

Appendix G1

KR preference questionnaires

SELF conditions

1. When/why DID you ask for KR during the first half of practice?
 - a. ☐ mostly after a perceived good trial
 - b. ☐ mostly after a perceived bad trial
 - c. ☐ after a perceived good and bad trials equally
 - d. ☐ randomly
 - e. ☐ other: _____

2. When/why DID you ask for KR during the second half of practice?
 - a. ☐ mostly after a perceived good trial
 - b. ☐ mostly after a perceived bad trial
 - c. ☐ after a perceived good and bad trials equally
 - d. ☐ randomly
 - e. ☐ other: _____

3. When did you NOT ask for KR?
 - a. ☐ mostly after a perceived good trial
 - b. ☐ mostly after a perceived bad trial
 - c. ☐ after a perceived good and bad trials equally
 - d. ☐ randomly
 - e. ☐ other: _____

Appendix G2

YOKED conditions

1. Do you think your received KR after the right trials?
 - a. ☐ YES
 - b. ☐ NO
2. If you answered NO to the above question, when would you have preferred to receive KR?
 - a. ☐ mostly after a perceived good trial
 - b. ☐ mostly after a perceived bad trial
 - c. ☐ after a perceived good and bad trials equally
 - d. ☐ randomly
 - e. ☐ other: _____

Appendix H

Intrinsic feedback questionnaire

Part One

1. During practice, did you use/interpret any other sources of information in addition to KR or when KR was not available?
 - a. ☐ YES
 - b. ☐ NO
2. If the answer to the above question was YES, please indicate all the sources you used/interpreted during practice.
 - a. ☐ hand position
 - b. ☐ wrist position
 - c. ☐ arm position
 - d. ☐ elbow angle
 - e. ☐ shoulder position
 - f. ☐ produced force
 - g. ☐ other: _____

Part Two

1. Please indicate whether the sources you used changed during practice and, if so, briefly describe the nature of this change?

[illegible]

Appendix I

Statistical results for acquisition

Effects	Dependent Variables	
	CE	VE
Main effects		
KR condition	$F(1,29) = 14.70, p = .001$	$F(1,28) = 7.39, p = .011$
Age	$F(1,29) = 59.76, p = .001$	$F(1,28) = 18.00, p = .000$
Block	$F(9,261) = 14.76, p = .000$	$F(9,252) = 12.17, p = .000$
Interactions		
KR condition x Age	$F(1,29) = 3.27, p = .081$	$F(1,28) = 4.26, p = .048$
Block x KR condition	$F(9,261) = 1.80, p = .068$	$F(9,252) = 3.77, p = .000$
Block x Age	$F(9,261) = .25, p = .986$	$F(9,252) = 1.44, p = .172$
Block x KR condition x Age	$F(9,261) = .80, p = .619$	$F(9,252) = .74, p = .675$

Note: Results were significant at $p \leq .05$

Appendix J

Statistical results for retention

Effects	Dependent variables		
	CE	VE	AD
Main effects			
KR condition	$F(1,34) = 7.04, p = .012$	$F(1,35) = 4.65, p = .038$	$F(1,34) = 7.30, p = .011$
Age	$F(1,34) = 18.36, p = .012$	$F(1,35) = 4.67, p = .038$	$F(1,34) = 45.52, p = .000$
Retention test	$F(1,34) = 7.73, p = .009$	$F(1,35) = 2.54, p = .120$	$F(1,34) = 2.53, p = .121$
Interactions			
KR condition x Age	$F(1,34) = 4.57, p = .040$	$F(1,35) = 12.02, p = .001$	$F(1,34) = 4.51, p = .041$
Retention test x KR condition	$F(1,34) = .00, p = .966$	$F(1,35) = .06, p = .814$	$F(1,34) = .01, p = .923$
Retention test x Age	$F(1,34) = .96, p = .335$	$F(1,35) = .76, p = .389$	$F(1,34) = .02, p = .903$
Retention test x KR Condition x Age	$F(1,34) = 1.88, p = .179$	$F(1,35) = .35, p = .560$	$F(1,34) = .05, p = .822$

Note: Results were significant at $p \leq .05$

Appendix K

Statistical results for transfer

Effects	Dependent variables		
	CE	VE	AD
Main effects			
KR condition	$F(1,33) = .13, p = .721$	$F(1,32) = .32, p = .579$	$F(1,34) = .08, p = .775$
Age	$F(1,33) = 20.11, p = .000$	$F(1,32) = 1.78, p = .038$	$F(1,34) = 20.88, p = .000$
Interaction			
KR condition x Age	$F(1,33) = .00, p = .988$	$F(1,32) = .05, p = .822$	$F(1,34) = .35, p = .556$

Note: Results were significant at $p \leq .05$

Appendix L

Means and standard deviations for all dependent variables for all conditions for acquisition, retention, and transfer

Dependent variables			
KR Condition	CE	VE	AD
SELF-YOUNG			
Acquisition	$M=17.54, SD=6.94$	$M=9.68, SD=3.47$	-----
Retention	$M=9.08, SD=0.03$	$M=5.75, SD=0.09$	$M=6.53, SD=0.74$
Transfer	$M=16.74, SD=8.78$	$M=9.31, SD=5.99$	$M=12.07, SD=6.01$
SELF-OLD			
Acquisition	$M=23.98, SD=7.82$	$M=11.07, SD=3.16$	-----
Retention	$M=22.02, SD=4.11$	$M=10.99, SD=1.18$	$M=15.58, SD=0.85$
Transfer	$M=35.31, SD=21.49$	$M=11.55, SD=3.90$	$M=20.08, SD=9.55$
YOKED-YOUNG			
Acquisition	$M=18.72, SD=3.66$	$M=10.87, SD=2.04$	
Retention	$M=18.79, SD=2.60$	$M=10.98, SD=0.65$	$M=11.51, SD=1.01$
Transfer	$M=15.19, SD=6.45$	$M=7.71, SD=2.42$	$M=11.45, SD=2.61$
YOKED -OLD			
Acquisition	$M=27.66, SD=4.11$	$M=13.79, SD=1.59$	
Retention	$M=22.91, SD=2.15$	$M=9.77, SD=0.87$	$M=16.17, SD=0.71$
Transfer	$M=33.88, SD=2.36$	$M=10.87, SD=8.82$	$M=21.86, SD=3.43$

Note: Acquisition – means and standard deviations are collapsed across the acquisition blocks (1 to 10). Retention – means and standard deviations are collapsed across retention test (immediate and delayed).